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THE
PORTABLE ENGINE

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THE

PORTABLE ENGINE:

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THE

PORTABLE ENGINE

ITS

CONSTRUCTION AND MANAGEMENT

A PRACTICAL MANUAL

FOR

OWNERS AND USERS OF STEAM ENGINES GENERALLY

BY

WILLIAM DYSON WANSBROUGH

Capio Lumen

LONDON
CROSBY LOCKWOOD AND CO.
7, STATIONERS' HALL COURT, LUDGATE HILL
1887

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PREFACE.

The introduction of the portable steam-engine in its present form, now more than a generation ago, at once furnished the solution of many industrial problems. Numerous attempts had previously been made to disencumber the steam-engine of the inevitable complication, mass, and solidity necessary for the development of power from steam of low or atmospheric pressure. The master mind of James Watt, whose whole career was a series of brilliant discoveries, was vehemently opposed to the use of high-pressure steam, and it was not until the Cornish miner, Richard Trevithick, triumphantly exhibited his "puffer" or high-pressure engine in successful work that the prejudice gave way, and the first step towards the portable engine was accomplished.

So essentially different were Trevithick's engines from anything that had preceded them, that the following description of one of them, written at a time when Cornish engines were still working with boilers wholly or partially of *stone*, reads not very unlike the description of a modern double cylinder engine: "Chappell's engine had two cylinders and a double crank . . . . the engines were fixed on the boiler

. . . . the piston-rod crosshead worked in guides fixed to the cylinder, connecting-rods went from the crossheads to the cranks. Steam was turned on and off by a four-way cock."

This engine, it seems, was furnished with a blastpipe, but whether or not this was made use of to cause an artificial draught does not appear. At any rate it is described as puffing so loudly that it could be heard for miles. In the account of another of Trevithick's engines about the same period, however, it is explicitly stated that "the steam puffed up the chimney."

These were not, it will be understood, actually movable engines upon wheels, but they were undoubtedly a considerable advance in the direction of portability upon the engines of Watt, Hornblower, and others, which were in most cases dependent upon the masonry and walls of the engine-house for the connection between the beam and the cylinder.

Trevithick's engines above referred to were, moreover, direct-acting; so that we have at this early date (about 1803) the essentials of a portable engine—high pressure, direct action, and forced draught.

The boiler appears to have been of cast iron, cylindrical, with a single wrought-iron tube passing through it, and to have been quite independent of brickwork foundations and setting, and the engine was attached to the boiler. The pressure would seem to have been about 30 lbs. above the atmosphere.

The next step in the history of the portable engine is represented by a machine designed by Messrs. Tuxford of Boston in 1839, the year of the establishment of the Royal Agricultural Society.

This apparatus was a portable combination of engine and thrashing machine upon the same frame, and was of 6-horse power. The first engine upon this plan appears to have been set to work in the autumn of 1842 with satisfactory results. Within a twelvemonth from the trial of this engine Messrs. Tuxford turned out six machines of this class, and afterwards about twelve more of the same kind, after which they found it better to separate the engine from the thrashing machine.

In 1841 the Royal Agricultural Society held their Show at Liverpool, when an engine upon wheels was exhibited for the first time, and with that engine the history of the modern portable engine may be said to commence.

This was a rotary disc-engine constructed by Messrs. Ransomes and Sims, of Ipswich, under the patent of Mr. Henry Davies of Birmingham. The engine had a vertical boiler and was carried upon a single pair of wheels, and could be drawn by one horse. The crank-shaft was provided with a universal joint, coupling it directly to the thrashing machine.

The judges' report states concerning this engine: "The Society is indebted to Messrs. Ransomes of Ipswich for what may be termed the greatest novelty of the meeting, viz. the exhibition of a portable steam-engine for the purposes of thrashing corn. . . . . The advantages of steam power for working fixed thrashing mills have long been acknowledged in the northern parts of England and Scotland, but we believe this is the first attempt to render it portable so that it may be transported from one part of a farm to another as easily and expeditiously as the present machine with horse works. . . . . By the peculiar construction of the boiler and method of disposing of the waste steam, danger of ignition from sparks seems to be avoided, and the judges confidently express their opinion that, with prudence, as great safety may be experienced in the use of this portable thrashing engine in the stack-yard as is now found to be the case with a fixed engine in the barn."

Notwithstanding this high commendation, however, much difficulty was experienced in persuading the farmers of that date that it was possible to work an engine of this kind with safety in their rickyards; but two years later the judges' report states in connection with the Show at Derby in that year that "the manufacture and use of travelling steam-engines has become a systematic business."

Successive improvements were developed year by year in the construction of these engines, and in 1851, at a competition held in the grounds of the Great Exhibition in Hyde Park, Messrs. Hornsby, of Grantham, were successful in carrying off the prize with their 6-horse-power portable engine, which is reported to have consumed about 6¾ lbs. of coal per horse-power per hour.

The history of the portable engine for the next ten or twelve years can be studied at length in the reports of the judges at the yearly trials of the Royal Agricultural Society. Glancing over these we do not find much variation in the form or type of engine exhibited, but it is interesting to note the continued increase in the number of engines sent for trial in successive years, and the regularly diminishing consumption of coal per horse-power, ranging from 10·78 lbs. per hour in 1849 to 2·79 lbs. in the year 1872.

Since the latter date no further trials have been held by the Society, but it is probable that the result mentioned has never yet been surpassed by any engine of the same kind. The engines manufactured by the leading makers of to-day do not differ visibly from those produced by them twenty years ago. The engines, and especially the boilers, are larger for their nominal power. They are manufactured upon a better system and in ever-increasing numbers. They are possibly better finished, and may be sold at a lower price; but in all its essential features the portable engine of 1886 is an exact *replica* of the engine of 1863.

In introducing to the public the present work the author desires to say that he is fully sensible that to any person even slightly conversant with the details of the steam-engine much of the explanatory matter in Chapter I. must appear absurdly simple. If, however, it effects its purpose of giving the uninitiated a clue to the remainder of the book, its prolixity may, it is hoped, be forgiven by those who stand in no need of its assistance.

Succeeding chapters are devoted respectively to a description of the elementary parts of a steam-engine under the head of "Units of Connection," and to an explanation of the various parts of the typical* portable engine and boiler, all of which are fully illustrated by numerous small engravings.

Chapters V. and VI. treat of the distribution of steam by the slide-valve, and of the indicator diagram; while the final chapter of the book, under the head of "Hints to Purchasers," gives some information as to the choice of an engine and its maintenance in working order.

---

* The engine described is purposely of a somewhat old-fashioned (but thoroughly good) type.

Since these chapters were written, an explosion of a portable engine boiler has occurred, which illustrates the necessity for the periodical examination and testing of boilers of this kind, and confirms in a remarkable manner the advice in the earlier part of Chapter VII. on the purchase of second-hand engines.

An account of this explosion, reproduced from the official report of the Board of Trade, is printed at the end of Chapter VII.

The author ventures to hope that in its own particular line the book may be found not unacceptable to buyers and owners of steam-engines generally, as well as to those more directly engaged in the construction or management of the portable engine.

LINCOLN, *November*, 1886.

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THE PORTABLE ENGINE.

CHAPTER I.

AN ELEMENTARY DESCRIPTION OF THE HIGH-PRESSURE STEAM-ENGINE AND THE LOCOMOTIVE BOILER.

THE Steam-engine is simply an apparatus for utilising the heat derived from the combustion of coal or other material. The only source of power is heat, and steam, or the gas evolved from boiling water, is found to be the most convenient and cheapest, though not the only, means of converting heat into actual *mechanical work.*

The vessel known as the locomotive* boiler is one of the most efficient contrivances that has yet been devised for converting heat into pressure. In this apparatus the fire is enclosed in an iron box which is surrounded on all sides, except the bottom, by water. The flame and heated gases of the burning fuel act directly upon the sides and top of this *fire-box,* but although in the best position for the rapid production of steam, and directly in contact with the fire, it is found that not more than one-third or one-half of the useful heat is absorbed by the firebox-plates, so that it is necessary to provide some means for further utilising the heat of the rapidly escaping gases. To effect this they are, as it were, strained through a series of small tubes, to which they impart a considerable portion of their remaining heat, so that on arriving at the *smoke-box* at the farther end of the tubes they (the gases of combustion) escape into the open air through the chimney at a temperature of not more than 250° or 300° Fahr. above that of the surrounding water, the heat of the burning fuel in the fire-box being some 3,000° Fahr.

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* So called because first used in the locomotive engine.

Were it not for the fact that hot water is lighter than cold, some mechanical means would have to be provided for stirring up the water contained in the boiler, that all of it might in turn have access to the heated surfaces of the fire-box and tubes, but the fact being that water expands when heated, a given quantity of hot water is consequently not so heavy as the same amount of cold water, and naturally the heavier descends and the lighter rises, and in this way a constant circulation is produced, so that all the water at one time or another is in contact with the heating surface.

Now water heated in an open vessel continues to become hotter until it reaches 212° Fahr., or the boiling-point, and after that the continued application of heat does not make the water any hotter, but is expended in the formation of steam. But in boiling water under pressure, as in the boiler of a steam-engine, it is found that the boiling-point rises with the pressure, so that at 60 lbs. pressure upon the square inch the temperature is about 292° Fahr., and at higher pressures still greater. The external surface of the boiler is carefully *lagged* with hair felt and wood, and these are encased in a sheet-iron covering, so that, as far as possible, the heat of the steam may be transmitted to the *cylinder* without any portion of it being lost by *radiation,* or uselessly heating the surrounding atmosphere; but in spite of all we can do, a good deal of the heat is lost in this way. This is obvious; for if the boiler could be so protected as not to lose any of its heat by radiation, its external surface would be cold to the touch, which is very far from being the case. This applies to all boilers of whatever principle and by whomsoever made. We burn fuel in a stove in order to radiate the heat and so warm the room—there we use the heat externally ; in the case of the boiler we burn fuel to produce an internal effect, and all sensible heat on the outside is a loss.

Now let us consider how to keep up the supply of water to the boiler.

As there is so considerable a pressure within the boiler, it is evident that the feed-water must be injected in a forcible manner, to overcome the resistance of the steam pressure. This is done by means of a force-pump called the *feed-pump,* the action of which may be explained in a few words.

In principle it consists of a cylinder or *barrel* with two doors or *valves,* one opening inwards, the other outwards. A *plunger,* or solid mass of metal, works up and down in this barrel, motion being given to it by the engine. The above-mentioned valves are each connected to a pipe; the valve opening inwards, to a pipe leading to the tub or cistern containing the water supply ; the valve opening outwards, to a pipe terminating in the boiler below water level. Suppose now the plunger to be in its lowest position, at the bottom of the barrel; upon its making an upstroke, there is a *vacuum* or empty space left in the pump. The pressure of the atmosphere, nearly 15 lbs. on the square inch, forces water *up* the *suction pipe* from the tub or cistern, and fills the barrel, and the moment the plunger begins to descend, the valve or door through which the water has just entered shuts, and the water, having no way of escape but into the boiler, is driven through the second valve or door by the forcible descent of the plunger, and as soon as the latter begins its upward stroke the last-named valve is shut by the pressure in the boiler, leaving the barrel empty, to be filled by the next stroke as above described; and this goes on continually, as long as the boiler requires feeding.

The position of the surface of the water in the boiler is generally made known to the engine-driver by the *water-gauge*, which is a glass tube having a communication with the boiler at its upper and lower ends, and in which the water is plainly visible. If the latter be suffered to fall too low, it is likely that the plates of the fire-box may be overheated and possibly even destroyed, though much of the risk of this has been obviated in most boilers by the introduction of a *fusible plug* in the roof of the fire-box, which melts and allows the water to escape and extinguish the fire when the water level becomes too low.

On the other hand, if too much water is present in the boiler, it causes the inconvenience of *priming*—that is, water escapes into the cylinder along with the steam, which is productive of two disadvantages at least: the first being that the presence of water in the cylinder in any quantity is extremely dangerous; and, secondly, that the water which is lost in this way is *hot* water, and its place must be supplied through the feed pump by water comparatively cold. In some instances this priming takes place when the water level is not too high, as when the interior of the boiler is dirty or greasy.

Before we leave the boiler there is one thing more we must consider, viz., what becomes of the steam continually being produced in the boiler when the engine is stopped and there is no demand for steam? Or what assurance have we that the steam shall not rise above the pressure at which it—the boiler—is intended to work?

It is evident that if the engine is stopped and the demand for steam suddenly ceases, we cannot instantly slacken the intensity of the fire, and if there were no escape for the steam it would soon reach a dangerously high pressure, and at length tear the boiler to pieces.

A valve, very similar to those upon the feed-pump, is placed on the top of the boiler, covering a hole leading to the steam space. This is called the *Safety-valve.*

Now, supposing we wish to keep the boiler working at a pressure not exceeding 60 lbs. per square inch, then upon each square inch of the surface of the valve exposed there must be a pressure of 60 lbs. applied either by a weight or a spring (upon fixed engines generally the former, and in the case of locomotives and portable engines the latter). Thus: if the valve has an area of 5 square inches there must be a pressure of 5 times 60, or 300 lbs. upon its upper surface, to balance the steam pressure within, and all the steam in excess of 60 lbs. will be discharged.

Now we come to the cylinder, or part of the steam-engine, where the pressure of the steam in the boiler is converted into *power*—which is pressure *in motion.*

Probably to a person entirely unacquainted with the steam-engine the readiest way to make a description of the cylinder intelligible would be to borrow Zerah Colburn's illustration of a cannon—a cannon closed at both ends, and containing a cannon-ball which could be alternately shot from one end to the other, and back again, by sudden flashes of high-pressure steam introduced at each end at the proper moment. A rod firmly fixed to the ball, and passing through one end of the cannon, would serve to communicate the sliding motion to any external apparatus we pleased.

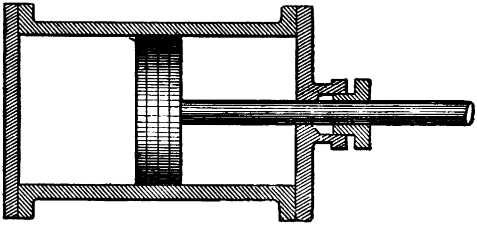

Fig. 1.—Scale: one inch to a foot.

Here is the cannon—which we shall in future call the cylinder, and the ball (reduced to a flat disc) attached to a rod, and to be known as the piston and piston-rod.

The cylinder is shown *in section,* that is, cut in half through the middle, with the piston laid in it.

If the reader is unaccustomed to this non-natural but most convenient manner of representing the interior of anything, it may be rendered somewhat more intelligible by the following views of a familiar object, given with the intention of illustrating the terms "section," "elevation," and "plan."

In this view it will be noticed that the whole cup (save a small piece broken out of it, the use of which will be explained presently) but only one half the saucer, is drawn. If the saucer were shown entire we should lose not only the view of the lower part of the cup, but we should not know the thickness of the saucer, nor even that it was hollow at all. The thickness is very clearly indicated, however, in the section: and that the cup is hollow and of similar thickness is shown by the piece broken out, which also gives us an opportunity of seeing a little more of the shape of the spoon. Now the piston and cylinder in Fig. 1 are respectively drawn in elevation and section as the cup and saucer are in Fig. 2.

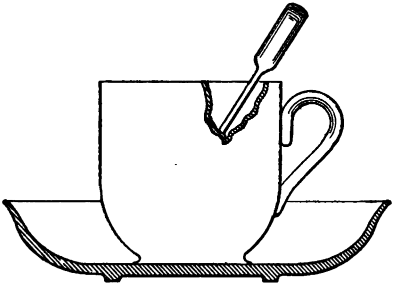

Fig. 2.—Scale: three inches to a foot.

Fig. 3 shows a "plan," or view seen from above, of the same articles. From this we see that both the cup and the saucer are *round*, which we could only infer from Fig. 2, from the way in which it was shaded.

Perspective views are not admissible in engineering drawings intended to illustrate accurately the object they profess to describe (and a drawing is nothing more than a short way of *describing* the object it represents) because a perspective view cannot be measured from.

Now the cup and saucer are drawn to a scale of three inches to a foot, or exactly one-fourth the natural size, and every part of the drawings can be measured, and from them a new cup and saucer might be made, exactly to match those from which the drawings were taken. Now we may, after this digression to explain the drawings, go on with our description of the cylinder. We thoroughly understand by this time that the piston, which fits the cylinder accurately, is driven backwards and forwards by the steam which is admitted alternately at the two ends of the cylinder by means to which we must now devote our attention.

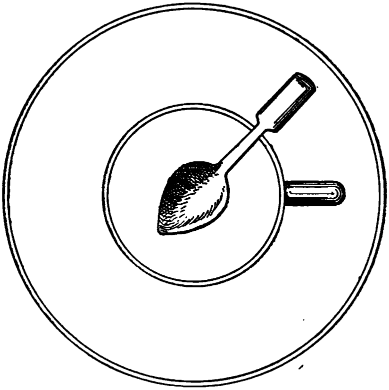

Fig. 3.—Scale: three inches to a foot.

This view of the cylinder, Fig. 4, is a more complete form than that in Fig. 1, and shows a little more of the apparatus employed for diverting the current of steam, which flows continuously from the boiler, alternately to one end or other of the cylinder.

In this section it will be seen that a box, called the steam-chest, is formed upon one side of the cylinder. If you were to take the lid A off the box, what you would see would be this.

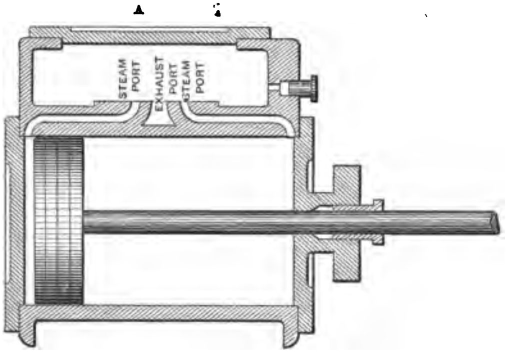

Fig. 4.—Scale: one inch to a foot.

Fig. 5 is a plan of the upper part of Fig. 4, and shows the inside of the steam-chest with three slits or openings made in it. These openings are really the mouths of three passages. The broad one in the middle leads straight out into the open air, and the side openings lead respectively to their ends of the cylinder. You will see them in Fig. 4 running along the top of the cylinder and coming down into it at the ends. The passages are called "ports." The steam-

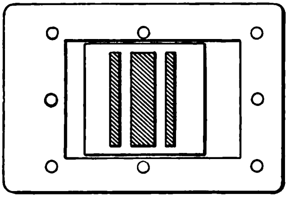

Fig. 5.—Scale: one inch to a foot.

chest is in free communication with the boiler, and of course is full of steam.

If now we cover up the middle port and one of the side ones, the steam will flow down the third into the cylinder and drive the piston and its rod right up to the other end; and if we had stopped the port by moving a sliding shutter over it, and could slide this shutter over the other one instead, without uncovering the middle port, it is evident that the piston would be moved back again by the pressure of the steam now admitted to the other side of it. Now this is exactly what happens in the steam-chest: this sliding shutter is continually moving backwards and forwards, and uncovering each port alternately, and in response to this the piston is driven backwards and forwards by the steam thus admitted to the cylinder. Thus far we are perfectly clear on the subject. The next question is, how is the steam which has propelled the piston got rid of? The moment it has done its work, it must be let out of the cylinder to allow of the piston coming back again.

Fig. 6 shows the complete cylinder with the shutter, called the *Slide-valve,** drawn in its place in the steam-chest.

It will be seen that the port leading to the back end of the cylinder is now wide open, and that by the simplest possible means, merely making a hollow place in the bottom of the slide-valve, a way is opened for the used steam, which is left in the other end of the cylinder, to escape into the open air. This it is which causes the intermittent "puffs" of steam, seen coming from the chimney of a railway engine, and the force with which this waste steam is ejected up the chimney draws a strong current of air through the fire, which many times increases its intensity, by the artificial draught thus produced. A rod, seen passing through the wall of the steam-chest is attached to the slide-valve, and the rod is connected to a part of the engine which gives it exactly the right movement. So that two cylinderfuls of steam are used each time* the wheel of the engine makes a revolution, or goes once round.

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* The slide-valve here shown differs slightly from that actually used in steam-engines, details of which are fully entered into at pp. 88—97.

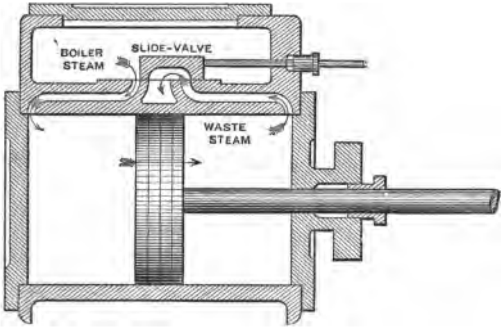

Fig. 6.—Scale: one inch to a foot.

Now having the pressure in the boiler translated, so to speak, by the cylinder, into a backward and forward motion of the piston-rod, it is easy for the most unmechanical reader to conceive how this is connected to a crank and a fly-wheel, exactly in the same way that the up-and-down motion of the foot in a sewing

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* By the improved form of slide-valve, illustrated and described at pp. 88—97, considerably less steam is used, and advantage taken of the property of expansion possessed by the steam.

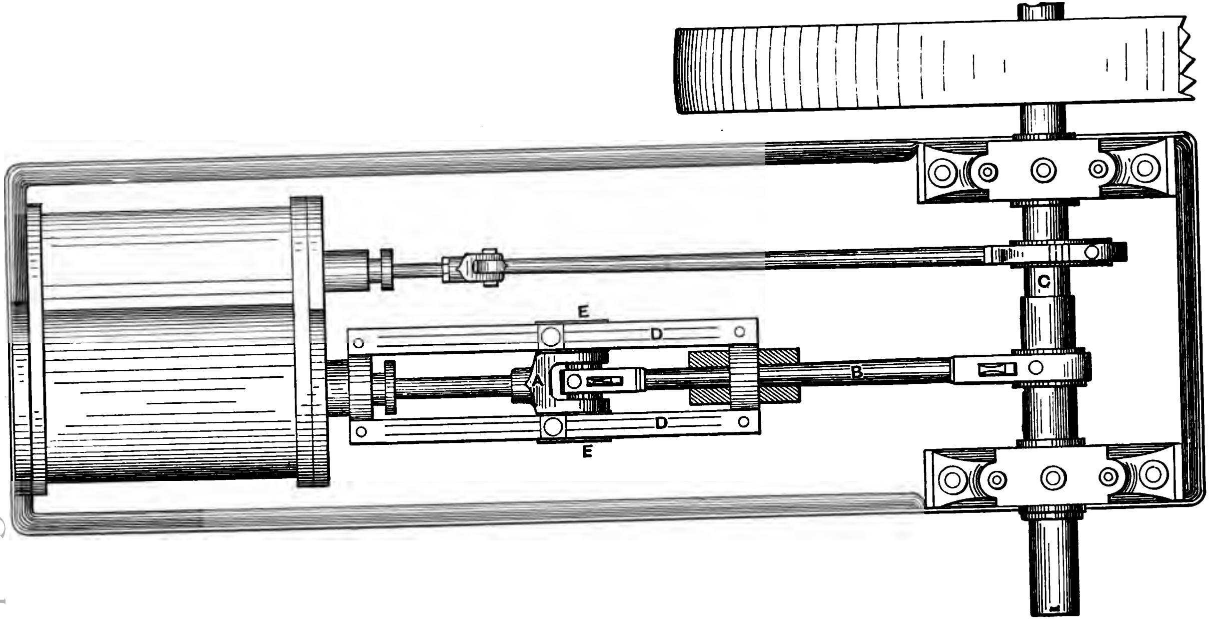

Fig. 7.—Scale: one inch to a foot.

machine or a foot-lathe is changed into the circular motion which serves to drive the machine.

Fig. 7 represents a complete steam-engine in plan—that is, as it appears when seen from above, and Fig. 8 shows the same engine seen from the side. In Fig. 7 the crank C will be recognised in a moment—a joint A is fixed upon the end of the piston-rod, and a rod B, called the connecting-rod, communicates the motion to the crank. The guide-bars D D, Figs. 7 and 8, are flat bars of metal between which slide flat square blocks E E, attached to the joint or *crosshead* A. This arrangement is to insure that the piston-rod shall move in a straight line, and not bend under the strain, which it would be certain to do were it not for the guide-bars.

Now with the exception of the arrangement for working the slide-valve, we understand the entire working of the engine. Upon the crank shaft at C is placed a small wheel, which has the peculiarity of being placed, unlike most wheels, "out of centre," so that it appears to bob up and down as the crank shaft revolves. This is called the *excentric sheave.* By placing a band round this, and connecting it to the slide-valve rod by another connecting-rod and a joint, we have the requisite to-and-fro motion communicated to the valve without further trouble. An exactly similar excentric sheave, band, and rod are used for working the plunger of the pump for feeding the boiler.

At the holes where the piston-rod and valve-rod pass out of the cylinder and steam-chest respectively, there is a contrivance called a *stuffing-box,* shown in Fig. 1, Fig. 4, and Fig. 6, to keep the steam from leaking out around the rods. The stuffing-box is, as its name implies, for the purpose of retaining some

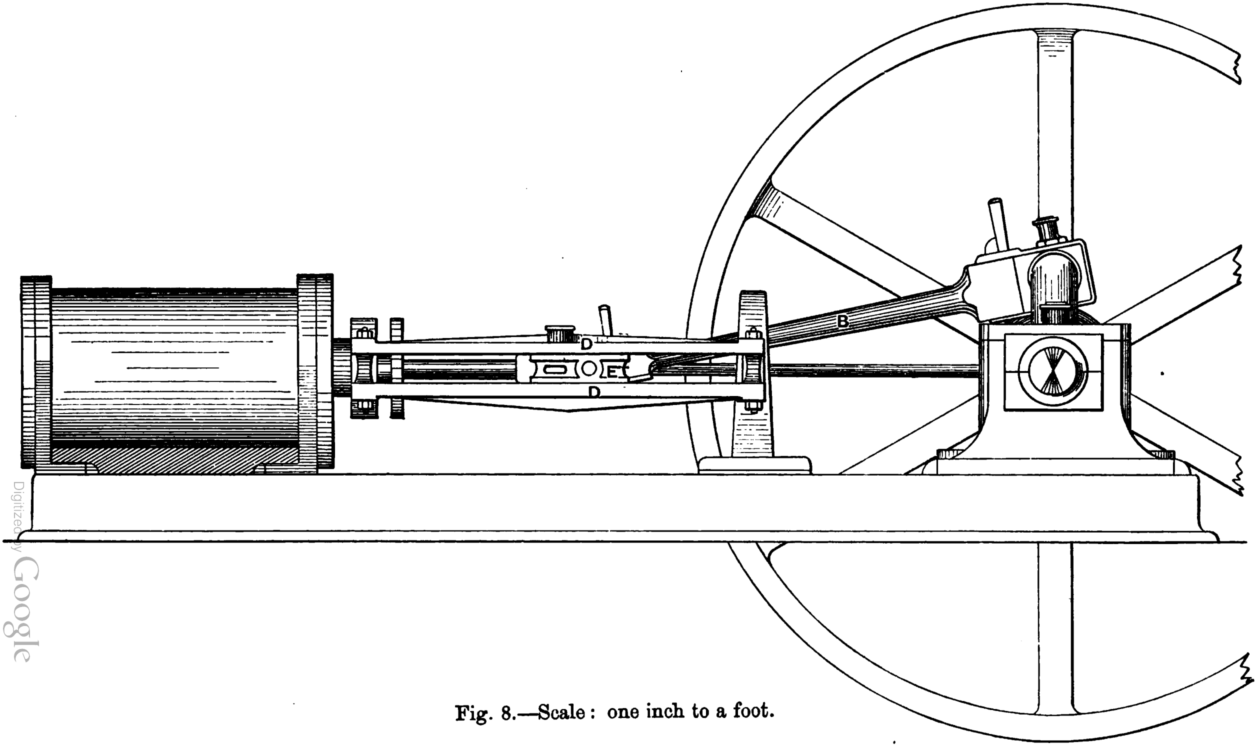

Fig. 8.—Scale: one inch to a foot.

soft material packed round the rod, by which the escape of steam can be prevented. This "packing," which is generally composed of well-greased hemp, or some such material, is kept pressed in its place by a gland or cover, usually made of brass, which is screwed down upon it. This arrangement allows of the rod working in and out quite easily, but effectually hinders any escape of steam.

Thus we have in the merest outline, and in the simplest language, endeavoured to sketch the essential details of the high-pressure steam-engine and the locomotive type of boiler, as they are combined in the portable engine. The bulk of our readers will, of course, require no such assistance to enable them to follow our remarks in the succeeding chapters, but we trust that they will not consider the few pages devoted to this A B C of the steam-engine as wasted if the remainder of the book be, by their help, rendered intelligible even to one reader out of a hundred.

CHAPTER II.

UNITS OF CONNECTION.

Before proceeding with the chapters upon Construction, it may be convenient to devote a few pages to an examination of the different devices almost universally employed for connecting together the numerous small parts of which an engine and boiler are built up, in most of which the screw (or the inclined plane, which is an unrolled screw) plays a more or less important part. The exceptions to this rule are the joint-pin, the rivet, and (as an example of fixing by shrinkage) the wheel-tyre.

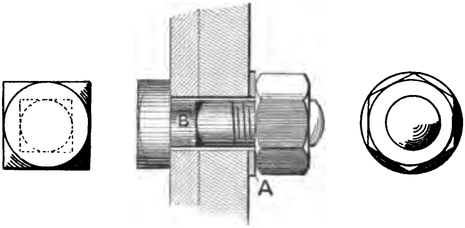

Fig. 9.—Bolt and Nut.

Simple Screw-Fastenings.

The bolt and nut.—The simplest form of bolt and nut is shown in Fig. 10. The stem is of circular section throughout, and (where used in steam-engines) is usually turned accurately to fit the holes through which it passes, so that the parts connected by it can have no *side shake*, even before the nut is tightened. The head of the bolt and the nut are made equal in thickness to

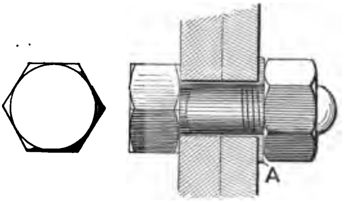

Fig. 10.—Bolt and Nut.

the diameter of the bolt, and shaped to a regular hexagon, and are usually case-hardened to strengthen the angles, which otherwise would soon give way under the action of the spanner, or key, Fig. 11. A *washer* A, or thin, flat iron ring, is often placed under the nut, to protect the surface beneath from abrasion from the sharp corners of the nut.

Example.—The long bolts through the connecting-rod straps, at Figs. 45 and 48, Chap. III. Where the

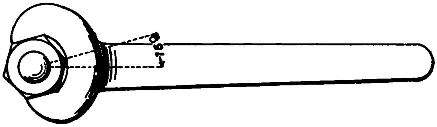

Fig. 11.—Spanner.

spanner cannot be used upon the head to prevent the bolt from turning round, while the nut is being screwed up, the form of bolt shown in Fig. 9, may be employed. The head is shown square and flat, but its form is immaterial, the principal feature being the square part under the head, at B, which fits in a *square* hole in one of the parts to be united. This form of bolt is much used for fixing the different details to the boiler, in which case an india-rubber ring is slipped on under the head, to form a joint with the inside of the boiler-plate.

Example.—The bolts at *b b* in Fig. 37, Chapter III., which fix the regulator-box to the boiler.

Fig. 12 represents a screw. This is identical in form with the bolt, Fig. 10, but is differently used, being screwed directly into one of the parts without the use of a nut.

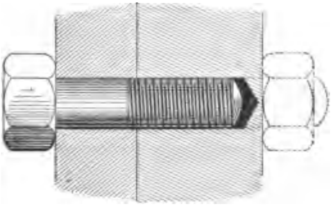

Fig. 12.—Screw.

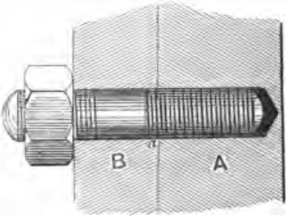

Fig. 13.—Stud.

Example.—The screws uniting the follower-plate and piston-body at F F, Fig. 43, Chap. III. Occasionally the screw passes quite through the part it is screwed into, and a *lock-nut* is tightened upon the protruding end, as in the dotted part of Fig. 12, in which case the sole difference between the screw and lock-nut, and the ordinary bolt, Fig. 10, lies in the fact that the former is *screwed* into one of the parts, whereas the latter is simply passed through both. The leading feature in this form of connection consists in the facility it gives for rigidly tightening the screw by the lock-nut without necessarily pressing the two parts together more than may be desirable.

Example.—The screws in the excentric-straps, Fig. 51, Chap. III. In this example the two halves of the excentric strap do not meet by an eighth of an inch, to allow for setting up when worn. By means of the screw-and-lock-nut, however, the two half-straps can be adjusted with the greatest nicety, and then fixed in that position by the lock-nuts.

The stud, Fig. 13, is one of the most useful of screw connections. It consists of a cylindrical piece of iron or steel, threaded at each end, with a plain portion between, which is usually turned to an exact fit for the hole in B, Fig. 13. The stud is tightly screwed by an instrument known as the *stud-driver*, into the part A, and the screw-thread upon that part of the stud which enters A, must be so tight a fit that it will not unscrew when the nut is being taken off. In all cases where a stud can be used, it is preferable to the screw, Fig. 12, especially where the parts are likely to be often taken to pieces, or when one of them happens to be the boiler-plate; for this reason, a screw, if often screwed in and out soon wears away the *thread* in the cast-iron, or thin boiler-plate, or whatever it may be screwed into. A stud, once in, is not disturbed again, and the nut may be screwed on and off to any extent, without damaging anything more expensive than the stud itself, which can easily be renewed. The only inconvenience about the use of studs, is their liability to break off suddenly at their weak point, *a*, Fig. 13, if used too roughly, and as a rule, when a bolt can be used, it is generally better than a stud, as it is much more easily replaced when broken.

Examples of Studs.—The fastenings of cylinder and steam-chest covers (Fig. 34), the gland-studs at C (Fig. 38), and at *g* (Fig. 52) in Chap. III.

Lock-Nuts.—Where a single nut upon any bolt, screw, or stud would be likely to work loose, by reason of vibration, or of intermittent strain in the parts connected, a second nut (usually much thinner than the main nut) is employed, and the two turned one against the other in opposite directions, or *locked*, as it is termed. This arrangement is also particularly useful in the case of studs for holding down glands, which may not be tightened down hard, but where, nevertheless, the nut must on no account work loose.

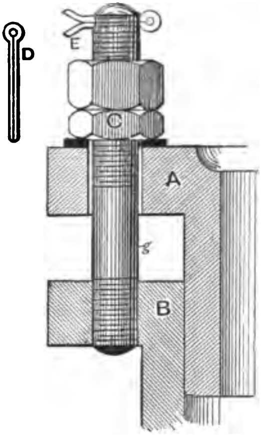

Fig. 14.—Lock-nuts.

Fig. 14 shows on a large scale, as an example, a portion of the gland A, and the pump-flange B, taken from the drawing of the pump (Fig. 52, Chap. III., already referred to). The stud is marked *g* in both figures. It will be noticed that the thin nut C is placed *beneath* the thicker one.

This is theoretically correct, but they are not often so placed in practice, as it necessitates the employment of a specially thin spanner to turn the lower nut. In many cases, indeed, the nuts are made of equal thickness, and to this there can be no objection. At the same time, it is just as well to understand how it is that the strain is taken by the *top* nut, and not by the bottom one. When two lock-nuts are tightened together they press one another in opposite directions. In the case of a stud standing vertically, the nut intended to resist an *upward* strain, *i.e.* to screw *down* the gland in Fig. 14, for example, ought to bear upon the *under* surfaces of the screw-thread upon the stud; and this is done by the *upper* nut of the two, whether it be the thick or the thin one, the under nut simply serving to jam it in the required direction—that is, *upwards.* The upper nut, therefore, being the one that exercises pressure in the required direction, should be the thicker of the two, if there is any difference.

Split-Pins.—As an additional precaution against the possibility of even lock-nuts working loose, a split-pin D (Fig. 14) may be inserted in a hole drilled for that purpose through the stud, and the ends are pressed open, as shown at E.

Example.—The nuts upon the cotter at F in Fig. 45, Chap. III.

In certain cases, when the head must not project above the surface, a screw with a head like that upon an ordinary carpenter's wood screw is employed, put in by a screw-driver.

Example.—The screws upon the quadrant E (Fig. 37, Chap. III.), by which it is attached to the front of the boiler.

COTTERS AND KEYS.

Cotters.—There are two kinds of cotters used in the construction of the portable engine—fixed and movable. As an example of the first kind we may take the cotter by which the piston-rod is attached to the crosshead (see Fig. 44, Chap. III.). In this case the piston-rod is coned or tapered where it fits in the boss of the crosshead, but in many cases a shoulder upon the rod is used instead of the taper, and we illustrate this form of it at Fig. 15. It will be noticed that the inclined edge of the cotter fits the rod in *front* at B only, and the boss at the *back* only, at A A. The taper of the cotter is very slight—about 1 in 13, and the width may be, if cotter and rod are *both* steel or *both* iron, $\frac{1}{5}$th of the rod's diameter. As a general rule the edges of the cotter and cotter-hole are rounded, which, although probably due to the fact that the holes can be cut by the slot-drill with round ends much more cheaply than with square, is nevertheless an advantage, as being not so liable to fracture from the corners. If the parts united by the cotter are in motion, or liable to vibration, a split-pin should be inserted in the small end of the cotter.

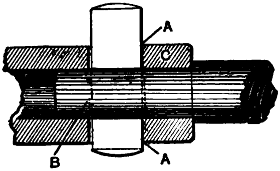

Fig. 15.—Cotter.

Movable Cotters.—These are much used to "set up" the brasses in connecting-rods, and in other situations where a screw would be inconvenient of application. A connecting-rod end, such as is used in the great majority of portable engines, is shown entirely in section at Fig. 16. In this form of "end" the closing of the brasses is effected by the action of the cotter in drawing the strap C farther upon the *butt* or square end of the rod. To provide a continuous bearing for the cotter to act upon, a *gib* D (Fig 16), having one edge inclined to suit the taper of the cotter, and a couple of projections upon the other edge designed to prevent the strap from "opening," is inserted in the cotter-hole, the projections D D being short enough to slip easily through the hole before the cotter is put in. Clearance at A, in the butt of the rod for the gib, and at

B B in the strap, is left to allow for the movement of the latter as the cotter is driven down from time to time.

At E a small *set-screw* is tapped into the butt to retain the cotter in place. It does not enter the latter, but only jams it. This screw, which has a very important duty to fulfil, is subject to the disadvantage common to all screws (see p. 19) of in time wearing out the thread in the butt, and to obviate this another arrangement, used by some makers of portable engines, is shown in Fig. 16 by dotted lines. A screw-end is formed upon the cotter, passing through a hole in a prolongation of the gib. A couple of nuts, above and below, afford an exact and reliable means of setting and retaining the cotter in the desired position.

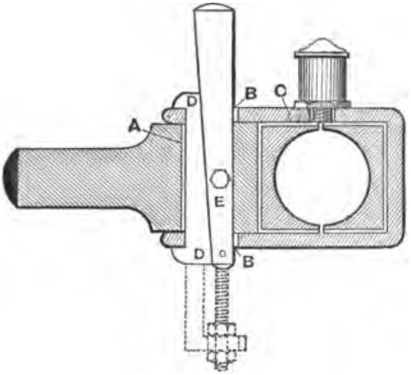

Fig. 16.—Cotter.

The taper of the cotter (and consequently of the gib) may be, for this class of cotter, as much as 1 in 10, but where the set-screw forms the only means of retaining the cotter in place, the taper should not be greater than 1 in 12. Another, and altogether a better, arrangement is illustrated at Figs. 45—48, Chapter III. In this case the strap, instead of being held together by the gib, is firmly bolted to the butt, and the cotter is only employed to set up the brass, the place of the gib being taken by a wedge-shaped rib E (Figs. 47 and 48), upon the brass itself. The inclined edge of the cotter is flat, to take a bearing upon the rib E, the other edge being rounded, to fit a groove cut down the end of the butt, in which the cotter lies for about half its depth. A screw-end and a pair of nuts upon the cotter afford a safe and reliable means of adjusting and fixing it. The taper may be as much as 1 in 8, without danger; but in this, as in all other cotters about a steam-engine, a split-pin through the end should never be omitted.

Keys and Key-ways.—When a wheel or pulley is to be fixed upon a round shaft, the plan of *keying on* is usually adopted. There are at least four different kinds of keys in common use, three of which are shown upon the same shaft in Fig. 17, though of course only as alternative arrangements.

The first, known as the *fluted* key, is shown at A. This key, which is necessarily of steel, is grooved upon its under side to a radius a little less than that of the shaft, into which, under the pressure of driving home, it slightly embeds itself at the edges A A. The form shown at B requires a flat place or *bed* to be filed upon the shaft for its reception, and is of course square in section. But neither of these two forms of key is to be relied upon for transmitting any great amount of power. A much better plan is shown at C, where the key-bed is formed as a shallow square groove in the shaft, of about one-fourth its diameter in width and one-eighth in depth. A groove of similar dimensions being cut in the wheel or disc to be keyed on, a steel or iron key, parallel as to its width and very nearly so as to depth, is driven up with a heavy hammer, and a most secure connection is attained. A head, *a* (Fig. 18), is often formed upon the key, especially where it cannot be reached by any instrument from the back, for driving out. A convenient tool, called a key-hook, is sometimes used for "drawing" headed keys. This is shown in Fig. 18. A taper pin, seen in dotted lines at *b*, inserted in a hole drilled through the shaft and split at the small end, obviates all chance of the key ever slipping out.

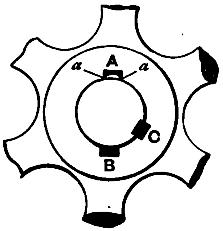

Fig. 17.—Keys.

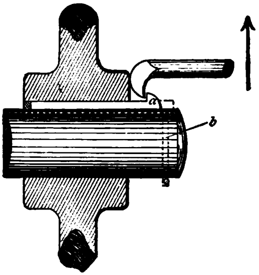

Fig. 18.—Key.

Examples of this key may be found in the fly-wheel at *a*, and pump excentric-sheave at *b*, in Plate I. (Fig. 1).

Keys of the kind we have been describing require a clear length of key-bed in the shaft at least equal to the length of the boss of the wheel or disc, *plus* the length of key, to enable them to be got in or out; and in certain cases so much room cannot be afforded, and a modification of the key called the *feather* is employed. The key-bed sunk in the shaft is no longer than the actual width of the boss; the key is fixed in the key-bed, and the wheel or disc driven into place upon it, exactly the reverse of the arrangement described just previously.

Example.—The expansion-plate in Fig. 51 (Chap. III.) is driven upon a feather. In some cases a set-screw is tapped into the boss, above the feather, with the point fitting in a shallow hole or recess, in the feather itself. This is usually done when there is a liability to move sideways.

An example of this may be found in the *mitre-wheel* Q, in the governor, Fig. 53 (Chap. III.) which is secured to the upright spindle in this manner, although the scale of the drawing is too small to show the detail.

Pin-Connections.

These may be either rigid or movable. Figs. 20, 21, and 22 illustrate three examples of the former class, and Fig. 19 one of the latter.

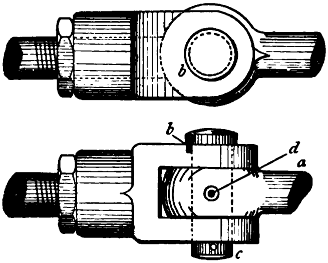

Fig. 19.—Pin-connections.

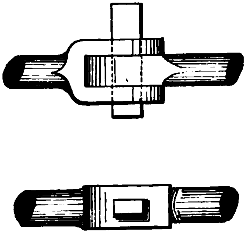

Fig. 20.—Pin-connections.

Fig. 20 appears at first sight rather to belong to the class of cottered connections, but in it the essential element of the cotter—the wedge—is wanting, and the seeming cotter is only a flat pin. There is no example of its use in the portable engine, but in Cornish or Lancashire boilers the longitudinal stays are often made in two pieces for convenience, and united in this way. Sometimes the hole in one or both parts is made longer than the flat pin; to allow of a certain amount of end movement, relatively to each other, of the two parts, to compensate for differences in the expansion and contraction of the boiler and the stay, the length being adjusted so that the stay pulls up tight when steam is up, and the pressure acts upon the boiler ends.

Figs. 21 and 22 are two slightly different methods used in portable engine boilers for attaching the longitudinal stays to the boiler ends. In the one case a T-iron, and in the other two angle-irons, are riveted across the boiler plate, and suitable ends being formed upon the stay-rods (of which there are usually four), connection is effected by a round pin.

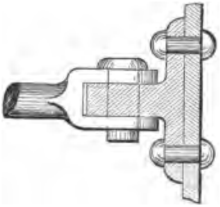

Fig. 21.—Pin-connections.

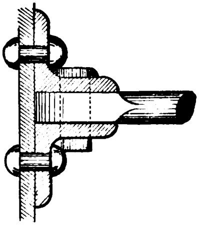

Fig. 22.—Pin-connections.

An example of the use of Fig. 21 will be seen in the longitudinal section of the boiler in Fig. 58 (Chap. IV.)

The foregoing are examples of what may be called *rigid* pin-connections, and they are generally left rough, as they come from the hands of the smith. A much more highly-finished article is required in the joints which form part of the motion of the engine, one of which is illustrated by Fig. 19. Here the pin is, of course, truly circular, and usually of steel, hardened.

The inner part of the joint *a*, Fig. 19, is in shape a globe, or ball, with the sides shaped flat. A steel plug is (or should be) welded into the globe, through which the hole for the pin is drilled, and the end is case-hardened, this being the part intended to move or oscillate upon the pin. In the double part of the joint (also case-hardened) a little key-way is cut, which receives a very small feather fixed in the pin, to prevent the latter from turning round. Movement endwise, or loss of the pin altogether, is prevented by the split-pin at *c*. Finally a small hole for lubrication is drilled at *d*, or other suitable point, according to the position of the rod.

Example.—The joint of the guide-piece and valve excentric-rod at E, Figs. 32 and 34 (Chap. III.).

An example of a *hinge-pin* will be found in the chimney-joint at *c*, in Plates I. and II.

Link-connections, or Coupling-rods.—These may be described with sufficient accuracy for the present purpose as short rods, having joints (generally similar to that last described) at both ends, and used for transmitting angular motion, or varying its direction, between two given parts in the same plane.

Examples.—The rod connecting the handles of the two relief-cocks upon the cylinder in Plate I. (Fig. 2). The arms C C in the governor, Fig. 53 (Chap. III.).

SPINDLES AND CRANK-ARM CONNECTIONS.

The Crank-arm and Spindle are often employed when it is desired to change the *plane* of angular motion as well as its direction. A spindle, or circular shaft, carried in a bearing, extends from the one plane to the other, and upon each end a crank-arm or lever is fixed. The movement received by one arm can, it is obvious, be given off by the other at any desired angle; and, by varying the radius of the crank-arms, the arcs moved through by the two arms respectively can be relatively varied to any extent. The circular arc-movement of the spindle must not exceed 120 degrees, however.

Examples.—The starting-handle, spindle, and crank-arm for working the stop-valve, D C and B. The throttle-valve, spindle, and crank-arm, F G and H, all in Figs. 37 and 38 (Chap. III.)

The *bell-crank* may be described as the two crank-arms, fixed together at the required angle, and of the proper relative lengths, either fixed upon a moving spindle or working upon a fixed stud.

Example.—The double lever L L′, in the governor for converting the vertical movement of the slide F into the horizontal motion of the coupling-rod actuating the throttle-valve, is a bell-crank, Figs. 53 and 54 (Chap. III.). For transmitting rotative movement from one to the other of two planes, which instead of being parallel to, are at an angle with, one another, toothed wheels gearing together, with the teeth constructed to suit the angle made by two spindles, would be employed. If the movement were angular (arc-movement) only, then instead of entire wheels, a couple of toothed sectors of suitable length of arc would be fixed upon the adjacent ends of the two spindles, and geared together just as the entire wheels would be.

An example of change of rotative movement from horizontal to vertical, by means of toothed wheels (called *mitre-wheels* when they form a right-angle, and the two wheels are of equal diameter) will be found in the governor, Figs. 53 and 54 (Chap. III.), where the two mitre-wheels are lettered Q and R.

Belt-pulleys.—An example also of the connection of two shafts in the same plane of motion, but with different speeds, will be found in the means employed to communicate motion from the crank-shaft to the governor. The mitre-wheel R runs loose upon the *stud* S, and to it is fixed the belt-pulley T, Figs. 53 and 54 (Chap. III.). A narrow leather belt, seen in Plate II., conveys the motion. The pulleys are perfectly smooth and slightly rounded upon their edge, and the respective speeds of two pulleys connected by a belt vary inversely as the diameters.

The plan just mentioned, of a wheel running loose upon a fixed stud, is not to be commended, on account of the difficulty of taking up wear in the centre hole of the wheel.

In a small detail like the governor-pulley, this is perhaps not of much consequence, but when carried out on a comparatively large scale, as in the road-wheels and axles, the result cannot be said to be altogether satisfactory, and it is fortunate that in the latter case mathematical precision of movement is not a matter of importance.

An example of a form of *Socket-connection* suitable only for compressive (not tensile) strain is shown in the *chimney-rest*, which fits into a boss upon the cylinder, and is kept from turning round or shaking out by a set-screw tapped into the side of the boss and bearing upon a flat place filed upon the corresponding part of the chimney-rest.

Stuffing-boxes and Glands.—To enable a moving rod or spindle to pass into, or out of, a steam-space without leakage, the device called a *stuffing-box* must be made use of. Fig. 23 shows this arrangement in section. It will be understood in a moment how the elastic *packing* at *a* is pressed round the moving rod or spindle A, by the gland B, which in its turn is forced downwards by the pressure of the two nuts *b b*. The flange B of the gland is usually oval in plan, and should be thick enough to resist the strain of the nuts upon it without bending. The recess for packing need not be more than half-an-inch all round larger than the rod in any stuffing-box about a portable engine.

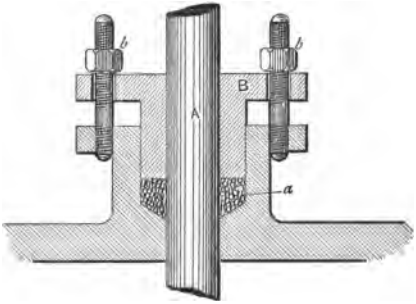

Fig. 23.—Stuffing-box.

Examples.—The stuffing-boxes for the regulator and throttle-valve spindles, Figs. 37 and 38. The stuffing-box upon the pump, Fig. 52 (Chap. III.).

Flange-connections.—A steam-pipe should never be screwed into a convex boiler-plate; the joint is difficult to make tight, and leakage—especially if unseen—tends to corrode the plate round the hole. A circular or oval flange, having a concave side to exactly fit the curve of the boiler, should be screwed upon the end of the pipe (which should stand through a little, so as to enter the hole in the boiler) and the flange secured by two, three, or more studs or bolts, according to size.

Example.—The delivery inlet to the boiler, on the pump, Fig. 52 (Chap. III.), secured by the round flange P, with three studs.

As another example of a flange-connection, though not upon a pipe, may be cited the *foot* or square flange by which the excentric-rod F is attached to the strap H, Fig. 51 (Chap. III.). The reason a flange-connection is employed in this case, instead of a cottered one, like that shown at Fig. 15 in the present chapter, is to allow of the lengthening of the rod F (in effect) by the insertion of thin plates of iron or tin, as packing, to compensate for the gradual wearing away of the strap H.

Pipe-connections.—The most convenient way of joining pipes so that they may be readily disconnected—and all pipes about a portable engine come under this classification—is by a pair of flanges, which may be oval, for two bolts and nuts.

Examples.—*Straight joints.* The exhaust pipe, where it joins the bend from the cylinder. The water-heater pipe, where it is connected to the valve-boxes of the pump.—*T-joints.* The junction of the water-heater pipe with the exhaust pipe at the base of the chimney. For all these see Plate I. (Fig. 2.)

Pipe Screw-joints.—Wrought-iron pipes for steam pressure may be permanently connected by *sockets.* Fig. 24 shows the ends of two pipes joined in this way. If neither of the pipes can be turned round in the socket, so as to screw it in, a screw-thread, a little longer than the socket A and the lock-nut together, is cut upon one of the pipes, and the nut first, and then the socket, screwed all the way on, as the dotted lines in Fig. 24. The two ends are then brought together, and another lock-nut having been placed upon pipe C, the socket is screwed partly off pipe B upon pipe C; and when fairly central upon the two pipes, a little hemp with red lead is twisted round each end of it at *a a*, Fig. 24, and the two nuts screwed up tight against this packing. Lock-nuts should be placed at both ends of every socket, in a steam pipe, as then, in case of leakage at a joint, the pipe need not be disconnected, as the nuts can be slacked back, and fresh packing inserted.

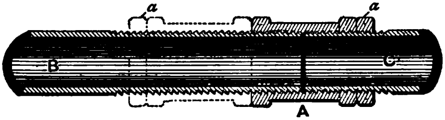

Fig. 24.—Pipe-connections.

For T-joints three-way sockets may be used in exactly the same way as the straight ones. The india-rubber pipes of the pump are secured by being wrapped with wire to brass ends, having loose nuts upon them to fit the screws upon the valve-boxes. This arrangement, which allows the pipes to be fixed or removed with great ease, is very clearly shown in section at D and M, Fig. 52 (Chap. III.).

Boiler Tubes.—Expanding.—These tubes, which are perfectly plain inside and out, are inserted into plain holes in the tube plate, and tightened by means of a tool called an expander, consisting of three little steel rollers *a a*, set in a ring *b*, Fig. 25. The ring, with the rollers just peeping out of three slots in the circumference, is placed in the end of the tube, and a taper pin or *mandrel*, *c*, is inserted in the central space between the rollers, and by means of a lever fitting in the holes *d*, in the head, is slowly turned round. The frictional contact causes the rollers to turn upon their own axes, and thereby to roll themselves round the inside of the tube, causing the rotation of the whole apparatus. By blows or pressure upon the head the taper mandrel is forced in until the required pressure is obtained upon the interior of the tube, which, by this rolling action, is so tightly fitted to the hole as to be perfectly water-tight under very considerable pressure.

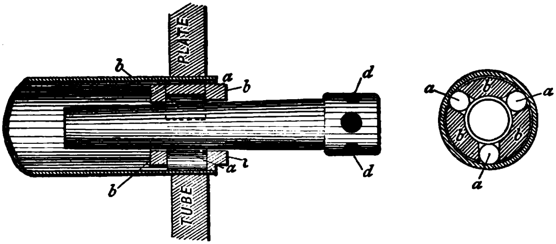

Fig. 25.—Expanding.

Formerly, a much ruder method was employed; a round piece of steel, slightly taper, and just large enough to enter the tube at its smaller end, was driven up by repeated blows of a heavy hammer, with the result often of tightening the tube under operation, but loosening those around it.

By the use of the expander, which requires only blows from a wooden mallet, all danger of loosening other tubes or of cracking the tube-plate is avoided.

Contraction: Wheel-tyres, &c.—Advantage is taken of the property of expansion when heated, possessed by iron and other metals, to fix the *tyres* or wrought-iron hoops upon the road-wheels. This operation, which is exactly the converse of that last described, is exceedingly simple.

The tyres are made just a shade smaller than the outer diameter of the wheel, when cold. Upon heat being applied to the hoop, it expands sufficiently to drop over the wheel easily. It is then cooled, by the sudden descent of the platform on which it is fixed, into a tank of water, and the tyre is found to have contracted upon the wheel so firmly that nothing short of cutting it through will remove it.

Another example of shrinkage may be found in the crosshead A, Fig. 44 (Chap. III.) which is shrunk upon the pin, or *gudgeon*, C, in exactly the same manner. (Occasionally the liner or working barrel A, Figs. 32 and 35 (Chap. III.) is put into the cylinder when the latter is heated, but the usual and far better plan is to force the liner in cold by the aid of a hydraulic press or a powerful screw.)

Contraction: Rivet-joints.—The same property of expansion is utilised in the means employed for uniting the plates of which the boiler is composed.

In Fig. 26 the overlapping edges of two boiler plates are represented. It will be seen that the holes for the rivet are conical, or taper (purposely exaggerated in the engraving), so that only the inner edges of the two plates fit the rivet. This is what may be called an accident of construction, and is due to the action of the punch, by which a small round plug of metal is forced out of the plate to form the hole. The rivet, as shown in Fig. 26, is inserted red-hot, and held up from below, and, either by a single hydraulic squeeze, or by a rapid shower of blows from the hammers of a couple of workmen, the straight cylindrical stalk is rounded down into a button, like the dotted line in Fig. 26, and forced to fill the double-conical hole. Now begins the contraction, and as the rivet cools the plates are gradually drawn together and a perfect joint is obtained, which is water-tight under the severe hydraulic test to which the boiler is subjected. The edges of the plates at *a a*, which should be *planed* to about the angle shown in the engraving, are generally slightly *caulked*, or set in by a kind of chisel with a blunt square edge. This, however, should be carefully done, or the edges may be forced asunder by the caulking-tool. The effects of over-caulking, somewhat exaggerated for the sake of clearness, are shown in Fig. 27.* This figure illustrates also another piece of bad workmanship—the rivet, it will be observed, does not fill the holes. In a section of a well-closed riveted joint, the line of demarcation between the rivet and plate should be almost invisible. Such a rivet, owing to the double conical hole, would continue to hold the plates in contact, even if both heads were broken off.

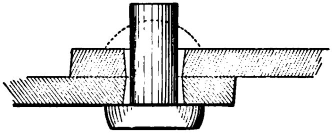

Fig. 26.—Rivet.

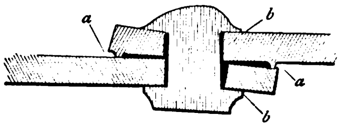

Fig. 27.—Rivet.

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* Copied from Mr. Robert Wilson's valuable "Treatise on Steam Boilers."

Another faulty rivet is shown in Fig. 28. The plates have not been closed together properly before the riveting, and the pressure upon the rivet has squeezed out a film of metal, *a*, between the two plates. Of course no amount of caulking would make a tight joint in such a case.

Fig. 29 shows another bad rivet, where the holes in the two plates do not coincide. This is a fault of very frequent occurrence in second-rate work, and the worst of it is, that in order to get the rivet in at all, the boiler-maker often makes use of a taper steel "drift," which is inserted into the holes, and by sheer force of blows is driven nearly through. What the condition of the edges of the plates must be after this treatment we may leave our readers to imagine.

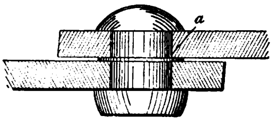

Fig. 28.—Rivet.

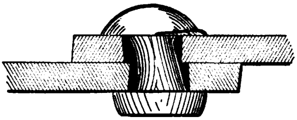
Fig. 29.—Rivet.

In ordinary cases, two holes which do not come fair should be "rimered out," and *never* drifted.

In portable engine construction the plates are usually punched from carefully prepared templates, in large quantities, and stocked ready for bending, and although the plates to form any individual boiler are taken at random from stock and put together, it is seldom that the holes fail to coincide. Drilled holes are never used in this class of work, but the punching done by properly trained workmen is almost perfection.

Proportions of Rivet-joints.—These may be either double-riveted or single-riveted, as Fig. 30 or Fig. 31.

The double-riveted joint is naturally much the stronger of the two, and is usually considered as equal to 70 per cent. of the solid plate, and the single-riveted joint as 56 per cent. Of course in proportioning rivet-joints the desideratum is to find such a diameter of rivet and such a pitch as shall make the rivet itself, and the section of the plate between the holes, as nearly as possible of the same strength, with perhaps a little excess upon the side of the plate, as it is usually of lower quality than the iron of which the rivet is made, and is more liable to corrosion and damage.

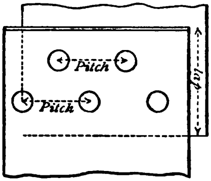

Fig. 30.—Double Riveting.

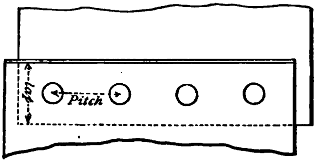

Fig. 31.—Single Riveting.

Mr. Wilson, in his "Treatise on Steam Boilers," gives the following table of diameters and pitches of rivets for pressures up to 160 lbs. per square inch. In either single or double riveted joints the distance from centre of rivet to edge of plate should be equal to one and a half times the diameter of rivet *hole*, and in the following table the diameter given is that of the *hole*, which is slightly larger than that of the rivet itself:—

TABLE OF DIAMETERS AND PITCHES OF RIVETS.

Thickness of Plate.	Diameter of Rivet.	Pitch. Single-riveted lap-joint.	Pitch. Double-riveted lap-joint.
in.	in.	in.	in.
$\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{3}{4}$
$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{5}{8}$	$2\frac{1}{4}$
$\frac{3}{8}$	$\frac{11}{16}$	$1\frac{3}{4}$	$2\frac{1}{4}$
$\frac{7}{16}$	$\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{1}{2}$
$\frac{1}{2}$	$\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{1}{2}$
$\frac{9}{16}$	$\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{3}{4}$
$\frac{5}{8}$	$\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{3}{4}$
$\frac{11}{16}$	$\frac{7}{8}$	$2\frac{1}{8}$	$2\frac{7}{8}$
$\frac{3}{4}$	1	$2\frac{1}{4}$	$3\frac{1}{4}$

A common proportion in portable engine boilers for 80 lbs. pressure and under is to use for $\frac{3}{8}$ plate, $\frac{5}{8}$ rivets at 2 inches pitch, which gives satisfactory results in practice.

CHAPTER III.

CONSTRUCTION.—THE ENGINE.

THE parts which comprise a portable engine may be all classed under two heads:—

I. The engine proper, comprising the cylinder, crank-shaft, connecting-rods, and moving parts generally, which form the subject of this chapter.

II. The boiler, ash-pan, chimney, and furnace-fittings; and the wheels and under-carriage.

We shall select a single-cylinder engine, as being the kind most commonly in use, and endeavour accurately to describe and illustrate the details of every part.

The Cylinder, illustrated by Figs. 32, 34, 35, 36, constitutes the principal part of the engine, and comprises a large number of details.

The lower part of the cylinder is curved so as to fit the boiler accurately, while the actual working barrel is formed of a *liner* or *bush*, A A, Figs. 32 and 35, of very hard cast-iron, forced into its place by hydraulic pressure. As will be seen from the section in Fig. 32, the liner and cylinder are only in contact at the ends, where the liner is externally of larger diameter, the recess thus formed, c c, Figs. 32 and 35, being in free communication with the boiler, thus *jacketing* the cylinder with a layer of high-pressure steam. The effect of the steam-jacket may be briefly summed up thus:—

When the steam in the cylinder is worked expansively to any extent, the temperature of the steam falls rapidly from the commencement of the period of expansion, and heat is as rapidly abstracted by the steam from the walls of the cylinder, thus cooling it, if unjacketed, down to something over the temperature of the escaping steam, only for it to be heated again the next moment at the expense of the next in-rush of steam from the valve-chest, and thus the cylinder is alternately heated and cooled. No amount of non-conducting covering can in the slightest degree arrest this action. If, however, a layer of live steam

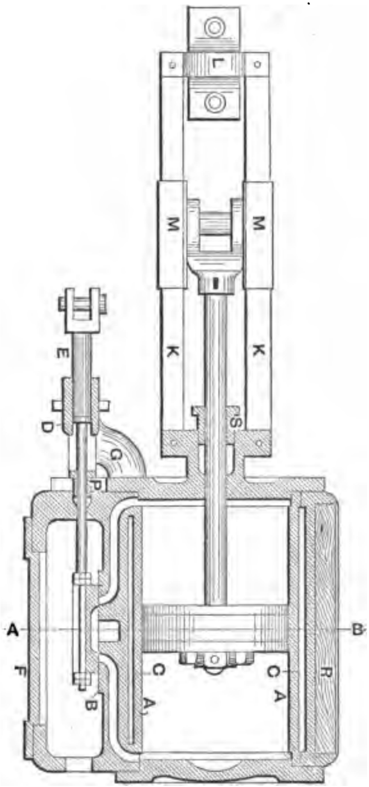

Fig. 32.—Sectional Plan of Cylinder. Scale: one inch to the foot.

from the boiler encircles the cylinder, the latter is kept as hot, or nearly so, as the boiler during the whole period of the stroke; the cooling during expansion, which, when confined to the cylinder, was sufficient to considerably affect the results, being in effect transferred to, and distributed over, the whole of the steam in the boiler, in which case the effect is too small to be of consequence, the whole amounting to perhaps a few drops of condensed water, draining back into the boiler from the jacket, per stroke.

The non-conducting material may, however, with great advantage be applied to shield the jacket from external cold, and it will be seen thus applied in the form of a wood covering round the cylinder at R, Figs. 32 and 35. It is, however, essential that the jacket be *really* filled with steam. There are thousands of "steam-jacketed" portable engines at work with jackets which, by reason of having no outlet at the top, are "air-trapped," and similarly, for want of a drain-pipe at the lowest point, are more or less filled with water, the intermediate space only containing steam. A jacket of this kind is much worse than useless. In many cases the safety-valves are placed upon the top of the cylinder in free communication with the steam jacket, and if the valves leak or blow off before the engine begins to work, the air is of course got rid of. This arrangement, however, is inconvenient in a cylinder with only external steam joints (such as the one we are engaged upon), as the supply pipe to the jacket must in that case be nearly as large as the main steam pipe. The author has recently, however, designed a simpler and much more effective arrangement, which, moreover, has the great merit of involving no additional cost whatever. The lower part of the steam jacket slopes slightly towards the pipe communicating with the boiler, and upon the highest point of the jacket, at the back of the cylinder, is placed the steam whistle, shown in detail at Fig. 33. In the lower part of the whistle is an inverted valve, which, by its own weight, remains open until the steam pressure rises sufficiently to close it. A perforated plate screwed into the bottom of the whistle prevents the valve dropping too far; and when the steam is up, the whistle may be used in the ordinary way by means of a string or small chain attached to the lever. By this device all the air contained in the boiler and steam-jacket gradually escapes through the whistle, and the valve closes automatically as soon as a pound or two of pressure has accumulated. The supply-pipe before mentioned permits of the condensed water returning to the boiler by its own gravity, and a jacket thus fitted may be relied upon as being a real "steam jacket."

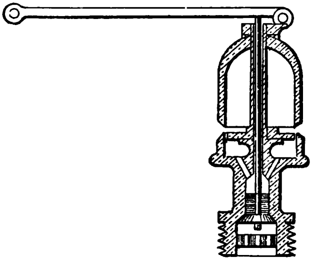

Fig. 33.—Scale: three inches to a foot.

A pair of *relief-cocks* are screwed into the lower part of the cylinder for discharging the condensed water while the engine is working. The handles are coupled together by a light connecting-rod, so that they are both opened and closed by one movement. The steam-chest or box containing the slide-valve is usually cast in one with the cylinder in modern engines; the troublesome and expensive plan of fixing a separate steam-chest to the cylinder by means of bolts having been long ago discarded.

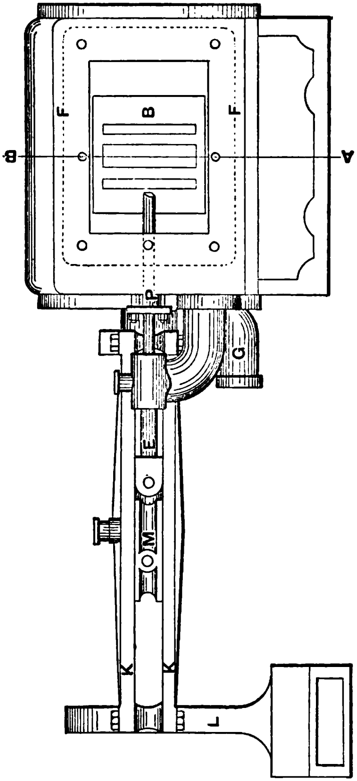

Fig. 34.—Scale: one inch to a foot.

The cylinder face, about which we shall have more to say presently, shown at B, Figs. 32, 34, and 35, is raised a little above the general level of the back of the steam-chest, and is long enough for the slide-valve to overlap it at each end of its travel, thus sweeping off any dirt or grit which might lodge on the face, and tending, as far as possible, to keep it from becoming concave under the continual wear of the valve.

The slide-valve, Fig. 36 (also to be further noticed hereafter), consists of a block of cast-iron (occasionally brass) one side of which, B, is deeply grooved for the valve-spindle C to lie in. The other side is an accurately-flat surface, except for the exhaust cavity A (also seen dotted in the end view D). The double nuts seen upon the valve-spindle form the shoulders, or collars, by which the valve is actuated. These nuts, each pair of which is tightly locked together, do not exercise any pressure endwise upon the valve, which is just a loose fit between them, for the reason that as the valve and cylinder face wear away, the valve gradually lowers itself from the spindle, which of course always retains its position.

The arrangement of stuffing-box and gland shown at

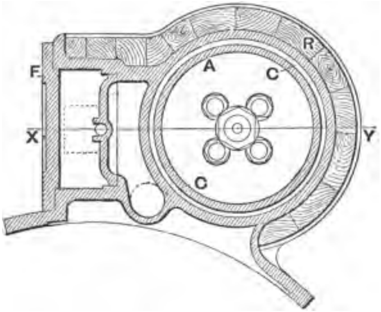

Fig. 35.—Scale: one inch to a foot.

P, Figs. 32 and 34, consists of a recess formed in the front of the steam-chest, about three-eighths of an inch wide all round the valve spindles, containing greased hemp or some other elastic packing, to allow of the movement of the slide-valve spindle, without at the same time permitting any steam to escape. This is compressed by the *gland*, a short tube of brass, having at one end an oval flange through which a couple of studs, screwed into the front of the steam-chest, pass. By means of nuts upon these studs bearing upon the flange of the gland, it can be screwed down as tight as may be necessary to prevent the escape of steam. The other end of the slide-valve spindle is screwed into a cylindrical piece, E, Figs. 32, 34, and 36, having a joint and pin at the other end for the excentric-rod. The intermediate part fits accurately, though freely, in the valve-rod guide D, Figs. 32 and 34, which is lined with a brass bush, easily renewable when worn. By screwing the valve-spindle in or out of the guide-piece E, the position of the slide-valve can be regulated with great exactness when the engine has steam up. On account of the expansion of the boiler this cannot be done while cold. The valve-spindle guide D is screwed to the front of the cylinder, leaving, however, sufficient room for the gland P to be withdrawn from the stuffing-box, when the latter requires repacking.

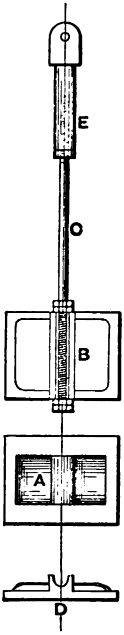

Fig. 36.
Scale: one inch to a foot.

The steam-chest cover F, Fig. 32, is also shown by the dotted line F, Fig. 34. The exhaust-pipe bend G, Figs. 32 and 34, is screwed into the front of the cylinder, and terminates in an oval flange, to which the remaining piece of exhaust-pipe reaching to the chimney is attached by a couple of bolts. Upon the top of the steam-chest is placed the *lubricator*, Fig. 39, which is a cylindrical vessel having a valve at the bottom and a movable lid, secured by a screw, for the introduction of tallow or oil into the cylinder.

The *regulator*, or stop-valve, and its box or casing, are shown in detail in Figs. 37 and 38. The valve itself, A, in both figures, is simply a flat brass shutter, capable of sliding up and down upon the planed surface of its seat, and actuated by the lever B, to which is connected by the spindle C the starting handle D, to limit the travel of which a brass quadrant, E, is affixed to the front of the boiler. The regulator-box, which is attached to the boiler by four bolts and to the cylinder by four studs, carries also the two safety-valves, which we shall describe directly.

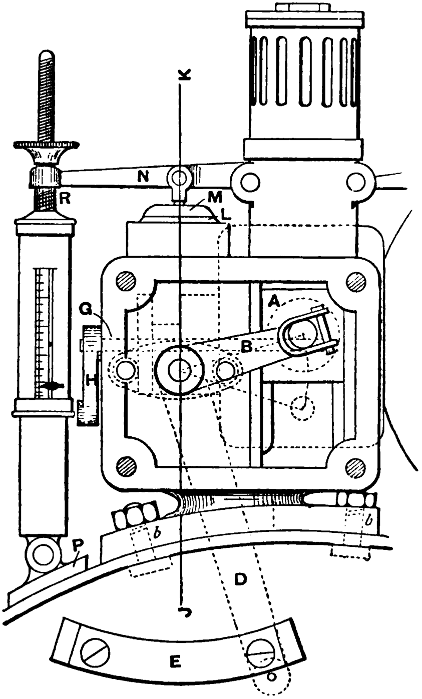

Fig. 37.—Scale: two inches to a foot.

The passage from the stop-valve leading to the steam-chest is accurately bored out, and within it is placed the throttle-valve F (through which the governor controls the speed of the engine), a flat plate of brass, nearly circular in form, so hung edgewise upon a thin steel spindle, G, that when its flat side is presented to the incoming steam, in the position shown in Fig. 38, the passage is stopped, but when turned a quarter round, nearly the full area of the passage is available. This

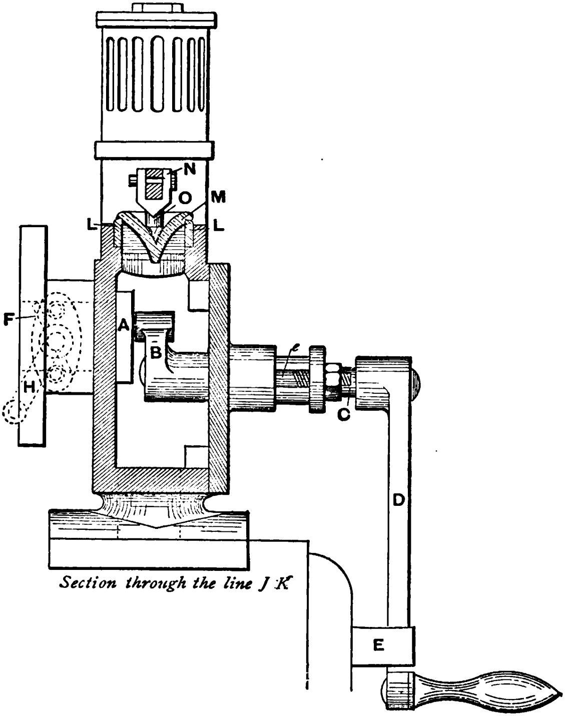

Fig. 38.—Scale: two inches to a foot.

arrangement is so clearly shown in Figs. 37 and 38, that it hardly needs further description.

The throttle-valve is connected to the governor by a small coupling-rod, the near end of which is attached to the lever H by a pin. When the governor is "up," and the engine running at full speed, the throttle-valve is nearly closed, opening wider as the speed is reduced and the governor drops. This form of throttle-valve, if hung exactly in the centre, is in perfect equilibrium, and the engine can be started or stopped by the movement of a finger. To ensure a prompt action of the governor, however, it is essential that the spindle be placed some little distance (about a sixteenth of an inch) below the centre of the passage, so that the valve being no longer in equilibrium will not remain shut if left to itself. A valve with the spindle placed centrally, or ever so little upon the wrong side of the centre (*i.e.* in this case too high), will cause the governor to "hunt" or rise and fall in quick succession continually, with corresponding irregularities in the speed of the engine. Too much attention can hardly be paid to the fitting of this little valve, as, unless it be nearly steam-tight when closed, the engine will not govern, and if the load be suddenly removed, or, when thrashing, if the feeding be interrupted for a moment, the engine will run wild and cause much inconvenience or even danger.

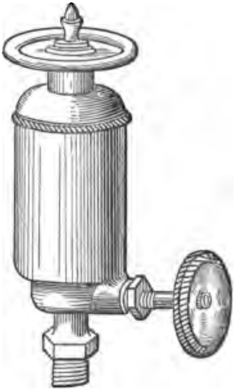

Fig. 39.—Scale: three inches to a foot.

In the earlier days of portable engines a regulator-case, containing the stop, throttle, and safety valves, almost exactly similar to the one we illustrate, was very commonly used, but for the sake of compactness was done away with, and the whole thing, somewhat modified in form, was put into the steam-chest and cast in one with the cylinder, a hole being cut in the top of the boiler, underneath the cylinder-base, by which the steam was admitted. This method of construction, which is still in common use, has these disadvantages: firstly, a possibility of unseen leakage, and consequent corrosion from the steam-joint under the cylinder; and secondly, a considerable increase in complication in the cylinder casting, already sufficiently complex. The transfer of all these smaller details to a comparatively inexpensive casting, such as the regulator-box, and the use of an external exhaust-pipe (saving another steam-joint under the cylinder), together with the practice of inserting a loose liner to form the steam-jacket, have very considerably simplified and cheapened repairs to portable engines, and most of the best engines now constructed are so fitted.

The upper part of the regulator-box with the two safety-valves has now to be dealt with.

The lever safety-valve is fully shown in elevation in Fig. 37, and in section in Fig. 38. A brass ring, L L, in both figures, is driven tightly into a seat bored for it in the top of the regulator-box, and upon the thin flat upper edge of this the valve itself, M, rests. The valve is guided by three wings, and has a conical depression in the centre, into which fits a pointed stem, O, formed with a joint at its upper end, and connected to the lever N by a pin. This gives a pressure *below* the seat, and greatly reduces the liability to "sticking." Advantage is taken of the proximity of the second or locked-up safety-valve to make its case serve as the fulcrum for this lever, which may either be pressed by a weight, as in Fig. 40 (in some foreign countries this is compulsory), or, as is usual in engines intended for home use, by a Salter spring-balance, the lower end of which is secured by a pin to a small bracket, P, screwed to the boiler.

A short piece of brass tube, B, cut to the proper length and slipped over the screw of the balance, prevents the nut being screwed down too far. The calculation of the length of lever required for a safety-valve is extremely simple, and may be stated thus: if the weight or spring-balance be equal to the intended boiler pressure in pounds, the distance L, Fig. 40, must be as many times the distance l as there are square inches in the area of the valve. If a weight or an incorrectly marked spring-balance be used, it must be weighed, and the following formula adopted: $L = \frac{PAl}{W}$, where $P =$ the intended pressure in pounds

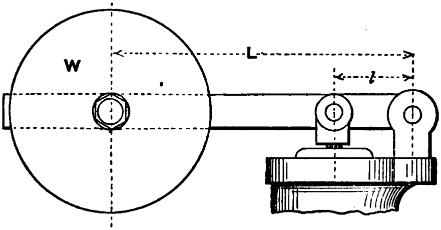

Fig. 40.—Scale: two inches to a foot.

per square inch, $A =$ the area of the hole covered by the valve, and $W =$ the weight. Or, having a given lever, the weight may be got from $W = \frac{P\,A\,l}{L}$. When W and P are equal, as in the case just mentioned, they disappear from the equation, which becomes $L = A\,l$.

An enlarged section of the locked-up safety-valve is given at Fig. 41. It will be seen that it is directly loaded by a spiral spring. A stem, A, tapering to a blunt point at the lower end, carries a flange, B, a little above the valve, upon which the lower end of the spring finds a bearing, the spring being pressed down, and the stem guided by a plate or diaphragm, C, having a fine screw-thread on the edge, which fits a corresponding thread upon the inside of the casing. This can be screwed up or down to adjust the pressure by a suitable key, which fits a couple of small holes drilled in the diaphragm. A cover of brass screws on over all, and is locked beyond tampering with by unauthorised persons by a small pin, D, secured by a padlock. Slots are cut in the sides of the casing to

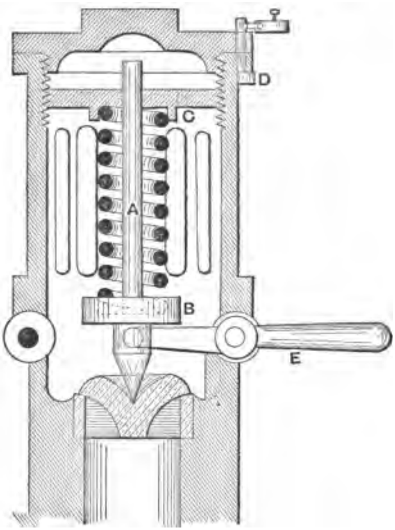

Fig. 41.—Scale: three inches to a foot.

permit the escape of the blown-off steam, and an easing-lever, E, so arranged that the valve may be lifted, but cannot be pressed downwards, completes the apparatus. This valve is usually adjusted to lift at about 5 lbs. per square inch above the ordinary working pressure.

To find the proper diameter of the round or square steel for spiral springs, the following rule * may be used :—

$$d = \sqrt[3]{\frac{S\,D}{C}} \quad \text{where—}$$

$d =$ diameter of the round steel, or the side, if square;
$D =$ mean diameter of spiral;
$S =$ total load on valve;
$C =$ a constant, viz. 11,000 for square steel, and 8,000 for round.

The length of the coiled spring should not be less than from 3 to 4 times its diameter.

The usual diameters of safety-valves for portable engines are about as follow :—

3 and 4	horse-power	1½	inch	diameter.
5 and 6	,, ,,	1¾	,,	,,
7, 8, 9, and 10	,, ,,	2	,,	,,
12 and 14	,, ,,	2¼	,,	,,
16 to 20	,, ,,	2½	,,	,,

The piston is of cast-iron, and consists of two principal parts, the piston proper, or body, A, Figs. 42 and 43, and the follower-plate B. The body is firmly secured upon the conical end of the piston-rod D by a large nut, and the follower-plate has a hole through it large enough to slip over this nut, and fitting the raised boss E upon the body, to which it is fastened by four screws, F F. A pair of cast-iron *piston-rings*, G G (shown in place upon the piston body in Fig. 42), are fitted so as to move easily, but without shake, between the two plates of the piston. It will be seen that at one point in the circumference of each ring a triangular notch is formed, and at the apex the ring is quite cut through. Forced up into the notch by a spiral spring is a little brass "glut" or wedge-piece, H, of circular section. The tendency of this is, of course, to wedge the ring asunder at the point where it is cut through, and thus the ring is expanded, to compensate for its own wear and that of the cylinder. The gluts in the two rings are placed diametrically opposite one another, and the rings are secured from turning round, relatively to each other or to the piston, by a small pin, J, driven into the side of each, fitting loosely in a corresponding hole in the side of each piston-plate. The rings are so constructed as to have of themselves a tendency to spring outwards, even when the glut-pressure is removed; and it is effected in this way: The ring, before being divided at the notch, is turned slightly larger than the bore of the cylinder it is to fit; a quarter of an inch or so is then cut out of it by a cutter like a very thick circular saw, and the cut closed quite up by external pressure, in which position the ring is finally turned to its proper diameter. By regulating the quantity cut out, the exact amount of natural spring required can be easily obtained. In

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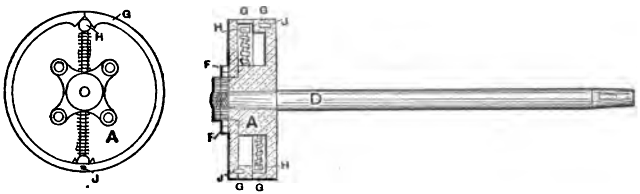
* Board of Trade.



Figs. 42 and 43.—Scale: one inch to a foot.

many engines this alone is relied upon for keeping the rings in close contact with the cylinder all round.

The piston-rod D, Fig. 43, is of steel, turned accurately parallel except at the ends, which are made conical to receive the piston and crosshead respectively. The amount of taper allowed is generally about 1 in 16; that is a reduction of a sixteenth of an inch in diameter for each inch in length. The piston is secured, as we have seen, by a large nut, which is kept from working loose by a split pin, shown in the section at Fig. 43 passing right through nut and screw.

The crosshead A, Fig. 44, is attached to the piston-rod by the cotter B, which is a flat piece of steel tapering edgeways, and an easy fit in the *cotter-hole* sideways. When the piston-rod is in its place in the crosshead and the cotter is inserted a very slight tap with a mallet upon the latter will draw the crosshead firmly upon the rod. The cotter has a split pin passed through it to prevent its working out, which would be attended with serious consequences. A good proportion for steel cotters in steel rods is: thickness of cotter $= \frac{1}{5}$ diameter of rod. The *gudgeon* C, a steel pin, is forced into the crosshead when the latter is nearly red hot, the contraction holding it immovably fast. Upon the large part C the connecting rod oscillates, and at the ends,

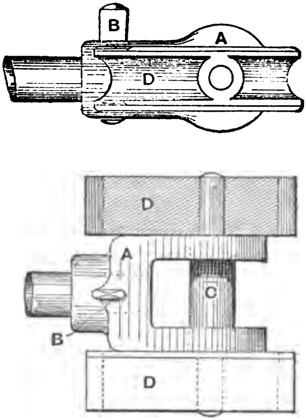


Fig. 44.—Scale: two inches to a foot.

which are turned down smaller for that purpose, the guide-blocks D D are fitted, as clearly shown in Fig. 44. These blocks, which are carefully fitted between the guide-bars K K, Figs. 32 and 34, are of course for the purpose of keeping the piston-rod during its movement in an exact line with the axis of the cylinder. They are secured at the ends to carefully adjusted distance-pieces formed on the front cylinder cover and the guide-bar stand L, Figs. 32 and 34. The guide-bars as well as the blocks are of cast-iron, and no provision is made for taking up wear, as it is found that if well proportioned and accurately fitted at first, and reasonably well lubricated when at work, the wear is almost inappreciable.

A simple rule for finding the pressure P upon the guide blocks is: where

a = area of piston;
p = the average cylinder pressure per square inch;
r = radius of crank in inches; and
l = length of connecting rod in inches:—

$$P = \frac{a\,p\,r}{l}$$

P should not exceed 36 lbs. per square inch of guide-block to ensure a perfectly satisfactory result. Oil cups are cast upon the two upper guide-bars at the centre of their length. The guide-bar stand calls for no special remark; it is clearly shown in the large plates and in the detail drawings, Figs. 32 and 34, and fulfils no other purpose than that of carrying the outer ends of the four guide-bars. A stuffing-box for the piston-rod to pass through is formed in the front cylinder cover. This is simply a recess round the rod of about half an inch in width, filled with packing,

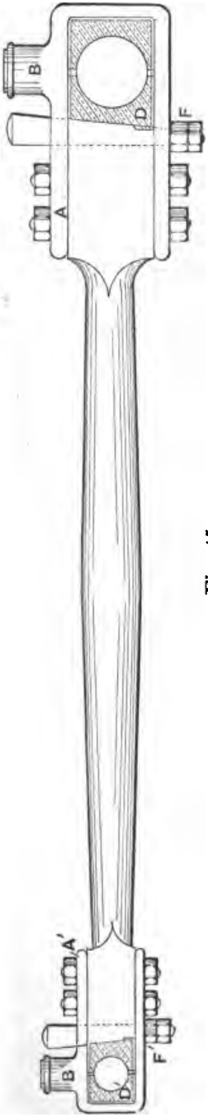


Fig. 45.

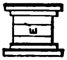


Fig. 46.

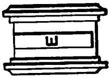


Fig. 47.

Scale: one and a half inch to a foot.

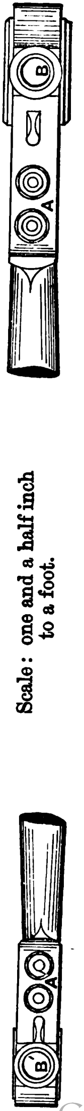


Fig. 48.

which is compressed by the gland, shown in its place at S, Fig. 32. The gland is, like the smaller one P upon the steam-chest, pressed down by two studs, screwed into the front of the stuffing-box.

The last of the details belonging to the cylinder which we have to consider is the chimney-rest, clearly shown in the large plates, which fits in a hole provided for that purpose in the top of the cylinder. The crutch at the top is of course intended to receive the chimney when lowered.

The connecting-rod, shown in detail at Figs. 45, 46, 47, and 48, is generally, in portable engines, from six to seven times the length of the crank, which is a very good proportion.

The rod itself is made of iron or steel and of circular section, except at the ends, which are of rectangular form. Upon these ends the *straps* A and A′, Figs 45 and 48, are accurately fitted to it, and secured each by two bolts. Oil-cups B B′ are formed in the straps, which are usually of malleable cast-iron. The brasses, as shown in section at D D′, Fig. 45, are divided vertically, and have a wedge-shaped rib or projection upon the half next to the cotter (more plainly seen at E E′, Figs. 46 and 47), by which they are set up, as the cotter is drawn downwards by the nuts F F′. The tendency of these connecting-rods is to become longer as the brasses wear, and provision has to be made for this in the cylinder by leaving about three-eighths of an inch *clearance* between the piston and the end furthest from the crank. Then as the brasses are set up from time to time, the piston gradually approaches the back cylinder cover. The crank-shaft, Fig. 49, is bent out of a round bar of steel, which has been previously swelled or thickened at the point A, so that the *journal*, or bearing, for the large end of the connecting-rod may be, when turned, not only as large in diameter as the straight part of the shaft, but be provided with shoulders of sufficient depth for the brasses to fit between. A couple of collars are forged upon the straight part, close to the crank, to form a journal for the main brasses upon that side. *Key-beds* or square grooves are cut up at B B on each end of the shaft for the fly-wheel, and, if necessary, an additional pulley at the opposite end, to be fixed upon it.

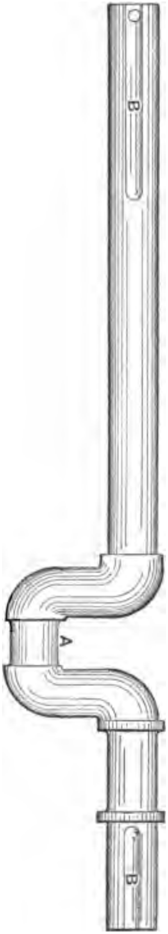


Fig. 49.—Scale: one inch to a foot.

The general appearance of the fly-wheel is clearly shown in the Plates, and the same may be said of the *saddle* or casting carrying the crank-shaft, of which a side view is given in Fig. 50. This is fitted to the boiler in the same manner as the cylinder. It will be seen that a cotter, precisely similar to those used for the connecting-rod, is employed to set up the brasses, which are of similar construction also. The cap fits over the bracket at the ends, thus securing it from end movement; and a couple of studs and nuts suffice to keep it down. The movable half of the brass, with its cotter, is placed nearest to the cylinder, in order to compensate as far as possible for the lengthening of the connecting-rod by wear as just now explained.

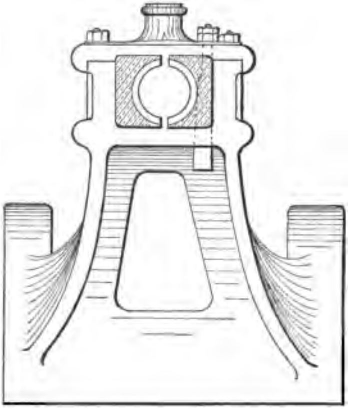


Fig. 50.—Scale: one inch to a foot.

Fig. 51 shows the arrangement for giving a variable position and travel to the excentric-sheave for working the slide valve.

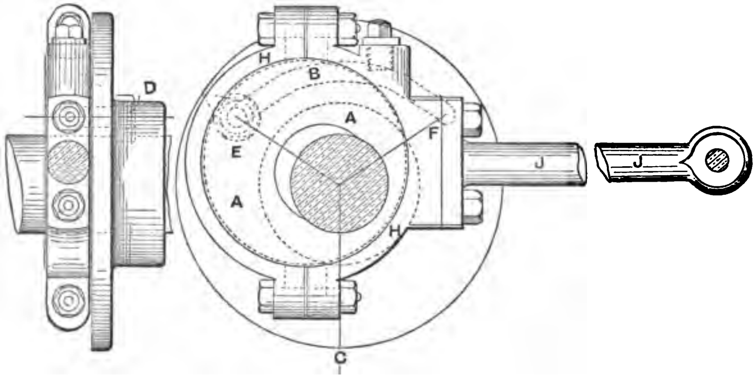


Fig. 51.—Scale: two inches to a foot.

The excentric-sheave itself, A A, Fig. 51, is simply a flat disc, with a grooved or concave edge, and having a hole bored through it (to fit the crank-shaft) exactly half as far out of centre as the intended maximum travel of the valve. This sheave, however, is not directly fastened upon the crank-shaft, but is clamped to a circular plate or disc, fixed to the shaft alongside it.

In this *expansion-plate*, as it is termed, a curved slot, B, Fig. 51, is cut diametrically opposite to the position of the crank C, and a stud or pin, D (seen in the side view, Fig. 51), screwed into the excentric-sheave, is passed through this slot, and by means of the nut at D the sheave can thus be fixed in any position between the points E and F. As the slot is not concentric with the crank-shaft, the hole in the sheave must be elongated to permit the requisite movement. If moved the entire distance, the motion of the engine will be reversed, and in intermediate positions the grade of expansion in the cylinder is varied. The considerations which determine the exact configuration of the slot in the expansion-plate will be discussed in a later chapter,* dealing with the proportions and movement of the slide-valve and the distribution of steam to the cylinder.

A brass or cast-iron *strap* or band, H H, Fig. 51, in two halves, bolted together, surrounds the excentric sheave, and to this the excentric-rod, J J (of which only the two ends are shown), is fastened by two studs and nuts. The other end of the excentric-rod fits the joint E, Figs. 32 and 34, upon the guide-piece of the slide-valve spindle, to which it is connected by a pin.

An exactly similar excentric-sheave (save that it has no expansion-plate, but is keyed directly upon the shaft), with strap and rod, is used for giving motion to the plunger of the feed-pump. Fig. 52 shows the pump in section. The body of the pump is, as will be seen, a comparatively simple casting, consisting mainly of a barrel, O, Fig. 52, and a large square flange, E, by which it is attached to the boiler. The plunger F works through a stuffing-box and gland at the top, but is otherwise a loose fit in the barrel. The excentric-rod G is connected by a pin to the joint H, at the bottom of the plunger, and through this it receives motion from the excentric-sheave already mentioned. The three valve-boxes, marked A, B, and C, are of brass and in one casting. The valves themselves are brass balls, truly spherical, fitting upon very narrow mitred seats, and limited as to their lift by a hollow brass plug screwed into the top of each valve-box.

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* See pp. 113—116, Chap. V.

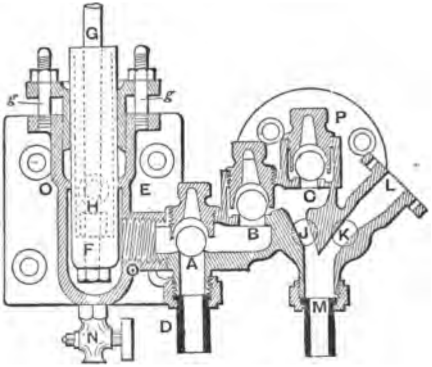

Fig 52.—Scale: one and a half inch to a foot.

The suction is at A, and the delivery-pipe is behind the valve-box C, attached to the boiler by the flange P. There is no stop-cock upon the suction-pipe, but when it is desired to reduce the feed to the boiler, or stop it altogether, the cock J is opened, and any required proportion of the water pumped can be thus returned to the vessel from which the feed-water is taken, through the union M, to which an india-rubber pipe is attached, a similar pipe (having, however, a spiral wire embedded in its substance to prevent collapse) being affixed at D for the suction. L is a branch communicating with the exhaust-pipe (for details of connection see Plates I. and II.), and K a stop-cock by which a portion of the exhaust steam may be allowed to pass down the pipe M, for the purpose of warming the feed-water. A *pet-cock*, N, is screwed into the bottom of the barrel for the purpose of draining the pump in case of frost, to prevent its fracture by ice. A *clearing plug*, opposite the passage into the boiler, permits of a wire being used to clear the delivery-pipe when steam is down. The capacity of the feed-pump should be equal to delivering at least double the amount of water which can be evaporated by the boiler; and with short-stroke pumps—such as the one we have described—the diameter of suction and delivery pipes and passages may be equal to one-half that of the plunger.

The last of the moving parts we shall have to notice is the governor. This is of the old slow-speed type, and though it has been to a great extent superseded by the numerous types of high-speed governors introduced of late years, it is nevertheless a very efficient and durable apparatus; and, if properly proportioned, sensitive enough to keep the engine at a very nearly uniform speed, whether loaded or running light. As a matter of fact, if the throttle-valve be properly arranged, almost any ordinary type of governor will act well, and the great majority of portable engines now running are fitted with the kind we illustrate at Fig. 53. The spindle A, in this figure, is of wrought-iron, having a

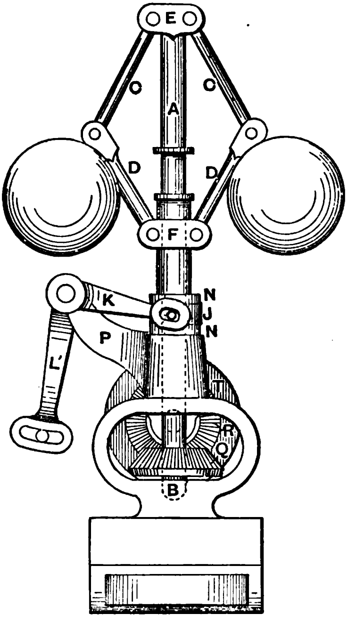

Fig. 53.—Scale: one and a half inch to a foot.

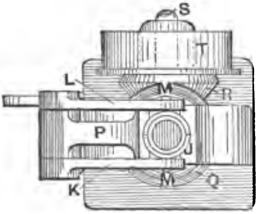

Fig. 54.—Scale: one and a half inch to a foot.

piece of steel welded to the *toe*, or lower end, at B. This is made as hard as possible, and revolves upon a similar piece of hardened steel let into the bottom of the stand, or bracket, at B. The top of the spindle is formed into a double joint, E, from which are suspended the arms C C, each carrying at the lower end a heavy cast-iron ball. A pair of links, or short rods, D D, connect the arms with the sliding *sleeve* F. The lower part of the sleeve, it will be seen, is furnished with a pair of collars, N N, and between these is placed a case-hardened iron ring, or *friction-collar*—seen better at J, Fig. 54—necessarily in two halves, and having a short pin, or *trunnion*, M M, Fig. 54, formed upon each half. The outer ends of a pair of levers, K and L, Figs. 53 and 54—one of which, L, has a second arm, L′, at right angles to it—fit upon the trunnions, and being connected together by a short spindle passing through the bracket-arm, P, the rising and falling of the sleeve is conveyed through the second arm, L′, by means of a long coupling-rod to the throttle-valve lever H, Figs. 37 and 38. The curved slot in the lever L′ is to allow for adjustment, the pin of the coupling-rod being free to slide within it until the correct position is found, when it is tightened up by a nut upon it. When properly adjusted, the throttle-valve should just shut when the governor is as high as it will go. A belt from the crank-shaft drives the pulley T, running loose upon a stud or pin, S, screwed into the governor-stand, and by means of the mitre-wheels Q and R the motion is transmitted to the upright spindle of the governor.

The speed at which a governor should be driven, depends upon the height of the cone of revolution, or, in other words, upon the vertical distance from a line drawn through the centres of the balls, to the point where the arms, being produced, intersect at the centre line of the spindle.

Let h = height of cone, and R = revolutions per minute required to just balance the weight of the balls by the centrifugal force.

$$R = \frac{187{\cdot}5}{\sqrt{h}}$$

The working position of the governor of a portable engine, when the engine is running at its proper number of revolutions, would be about half an inch below its highest range, and the height of the cone should be measured with the governor in this position.

Before taking leave of the engine, we shall have to examine the *boiler mountings*, or steam and water cocks and gauges. The safety-valves and the whistle have been already dealt with, as they are attached to the cylinder. We have now only to consider the steam-gauge and syphon, the water-gauge glass and cocks, and the blow-off cock.

Fig. 55 gives a view of a diaphragm steam-gauge, such as is ordinarily used for portable engines.

Between the two flanges under the dial is placed a very thin corrugated plate of steel, which receives upon its lower surface pressure from, and is thereby caused to bulge upwards to an extent proportioned to, the pressure beneath. The steel plate, or diaphragm, is connected by a slender rod, having a *rack*, or toothed portion at its upper end, to a very small cog-wheel or

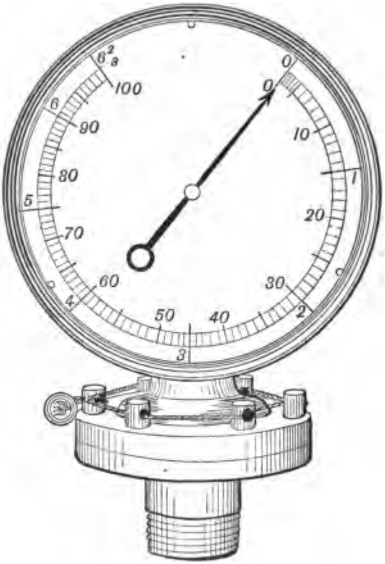

Fig. 55.—Scale: one half its original size.

pinion upon the axis of the pointer, and the whole is so contrived that the pressure within the boiler is indicated upon the dial with considerable exactness. To prevent the gauge being spoiled by the heat of the steam, it is placed upon a *syphon*, or bent tube, shown in Plate I. (Fig. 1), which owing to condensation remains always nearly full of cold water, through which the pressure acts upon the diaphragm.

In some cases the Bourdon pressure-gauge is used, which although very similar in external appearance to the one we have illustrated, differs totally from it in the way it is influenced by the pressure.

In the Bourdon gauge, a thin tube of oval section within the case is bent round into the form of the letter C. The tube, which is in communication with the boiler at its lower end, is at its upper extremity connected by a rack and pinion to the pointer, exactly as in the diaphragm gauge. When pressure is introduced into the C-tube, it assumes a tendency to straighten itself, which gives motion to the free upper end, and thereby to the pointer upon the dial.

Any one who has ever tried to bend a tube (such as a garden hose-pipe) into a circle of small diameter, will recollect that the tube manifested a troublesome tendency to collapse or become flat under the process. The action of the Bourdon gauge is the exact converse of this; the tube, which is already collapsed, being forced by the internal pressure to assume a form more nearly circular, and in doing this it necessarily unrolls itself more or less, and this is found to take place to an extent proportionate to the amount of pressure causing it.

The *water-gauge*, Fig. 56, consists of a pair of brass cocks, B and C, fixed upon the front of the boiler about equally above and below the water-line, and carrying between them a glass tube, A, in which the level of the water within the boiler is clearly visible.

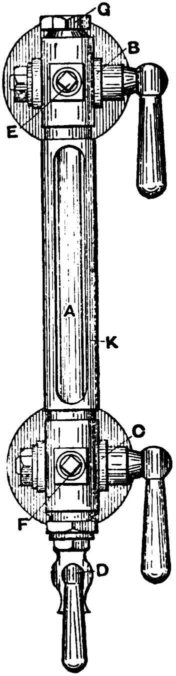

Fig. 56.—Scale: two inches to a foot.

The cocks B and C afford a means of shutting off communication with the boiler when necessary, and the smaller cock D below, called the *clearing-cock*, allows the glass to be *blown through* occasionally, for the double purpose of getting rid of scum or dirt in the glass, and of making sure that there is free communication between the glass and the boiler. Small clearing-holes with *screw-plugs*, E and F, are provided opposite the passages into the boiler, by which a wire or rod may be introduced and any stoppage removed.

In case of breakage of the glass tube, a new one may be inserted in two or three minutes by removing the screw-plug G at the top, and slackening the *screw-gland* at the bottom. The broken glass can then be taken out and a new one dropped in, and the gland tightened down upon an india-rubber ring, which forms the packing. There is no gland in the upper cock, the ring being simply slipped upon the glass and the plug G replaced. The steam pressure itself flattens down the ring and makes a perfect joint. To obviate as far as possible accidental breakage of the glass, and to prevent the fragments flying when a fracture does occur, a brass tube, K, with slits, through which the glass can be seen, is placed round it.

Gauge-cocks.—In case of the glass gauge failing to act for any length of time, recourse can be had to the two cocks upon the opposite side of the firebox, which will approximately indicate the position of the water-line. Steam will escape from both, when tried, if the water level be too low, and if too high water will issue. When the water is at its normal level, steam should show at the upper and water at the lower cock; but in all cases it is well to keep the glass constantly in order, as the gauge-cocks are only intended for temporary use. The lower one is placed about 2½ inches above the top of the firebox, and the other about the same distance higher.

The Blow-off cock, Fig. 57, will be seen in Plate I. (Fig. 1)—which shows the position of all these boiler fittings—at the bottom of the firebox, just over the ashpan damper. This is nothing more than a large brass cock with a hollow inverted plug, for the purpose of emptying the boiler, and calls for no remark.

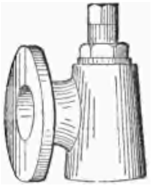

Fig. 57.—Scale: three inches to a foot.

Tables showing the principal dimensions of single and double cylinder portable engines, copied from the catalogue of a leading firm of manufacturers, are given below. This represents the latest practice in this class of engine, in which the cylinders are now made larger than formerly, so as to give the same power with fewer revolutions, and thus save considerably in wear and tear.

SINGLE CYLINDER ENGINES.

H. P. Nominal.	CYLINDER.		FLY-WHEEL.			
	Diameter.	Stroke.	Diameter.		Width.	Revolutions per Minute.
	in.	in.	ft.	in.	in.	
2½	5¼	9	3	6	4½	150
3	6¼	10	4	0	5	150
4	6¾	12	4	6	6½	120
5	7¾	12	4	6	6½	120
6	8½	12	4	10	6½	120
7	9	12	4	10	6½	120
8	10	12	5	0	7½	120
9	10½	12	5	0	7½	120
10	11	14	5	6	8	110
12	12	14	5	6	9	105

DOUBLE CYLINDER ENGINES.

H. P. Nominal.	CYLINDER.		FLY-WHEEL.			
	Diameter.	Stroke.	Diameter.		Width.	Revolutions per Minute.
		in.	ft.	in.	in.	
8	6¾	12	4	6	6½	120
10	7¾	12	5	0	7½	120
12	8½	12	5	0	8½	120
14	9	12	5	0	8½	120
16	10	14	5	6	9	105
18	10½	15	5	6	9	100
20	11	16	6	0	10	90
25	12	16	6	0	12	90
30	13	16	6	2	12	90

CHAPTER IV.

CONSTRUCTION.—THE BOILER.

THE boiler of the portable engine is always of the locomotive type, and, even in constructional details, rarely differs to any important extent from the boiler shown in Figs. 58, 59, 60, and 61. The essential elements of the locomotive boiler, the water-surrounded firebox, the numerous small horizontal flue-tubes, and the forced draught, have, through fifty years of engineering progress, remained unchanged, and stand to-day, as they did when exemplified for the first time in the "Rocket," in 1829, as an unrivalled combination, as the one form of steam-generator which has rendered possible the triumph of the locomotive over space, and transformed it from a sluggish cart-horse into an *Eclipse* with the speed of the wind.

Nor was its success, when applied to the use of the farmer, less assured, as it will be no less lasting, than in the case of the locomotive. The infancy of the portable engine was but a feeble one, until the happy idea was conceived of adapting to it the locomotive boiler; and from that time onwards the portable engine has been an established success, and no serious attempt has ever been made to supersede the form of

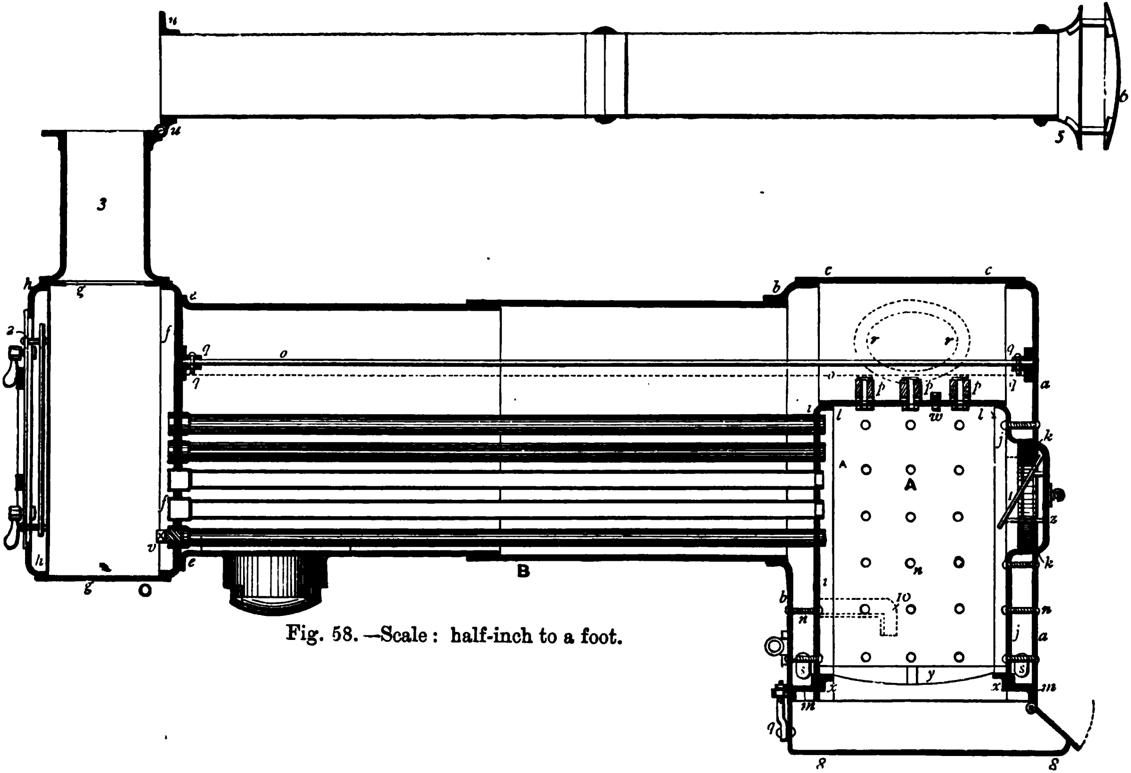

Fig. 58.—Scale: half-inch to a foot.

boiler which, it may be fairly said, launched it into real existence,

Before going into the details of its construction, it may be convenient, with the aid of the figures 58 to 61, to give a rough description of the boiler generally.

A then, in Figs. 58 and 61, represents the *firebox* in section, the bottom of which is formed by the *firebars* or grate. It will be noticed that the firebox is double, the space between the two walls being filled with water. To the outer firebox, called the *shell*, is attached the barrel B, the cylindrical part of the boiler, the lower half of which, as seen in the cross section, Fig. 60, is nearly taken up by a number of small flue-tubes, which serve to convey the products of combustion from the firebox to the *smokebox* C, upon which the chimney stands.

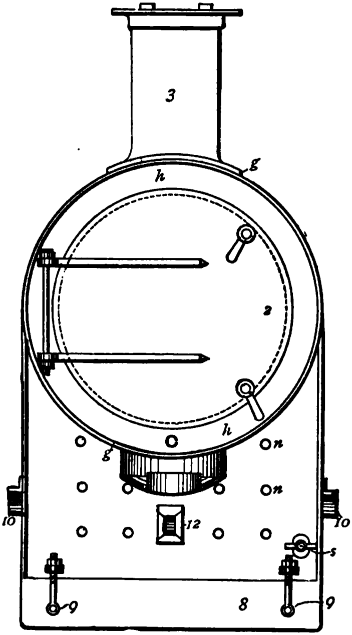

Fig. 59.—Scale: half-inch to a foot.

The fire is fed through the *firehole* D, and on account of the forced draught, induced by the action of the exhaust steam in the chimney, a very rapid combustion is obtained, the walls and roof of the firebox being heated by the direct action of the fire, and a further portion of the escaping heat being caught up and transferred to the water by the long tubes through which it has to pass before reaching the chimney. The water-level is indicated by a dotted line about two-thirds up the barrel.

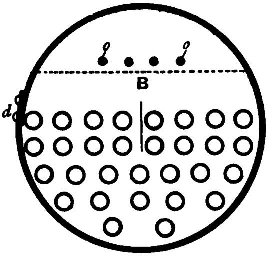

Fig. 60.—Scale: half inch to a foot.

A boiler of this kind contains very little water in proportion to the heating surface, and as a consequence steam is very rapidly got up—and as easily run down unless the firing is done regularly.

We shall now proceed to describe the boiler in detail, premising that our remarks are intended to apply more particularly to the smaller sizes of boilers, say up to and including 12 horse power.

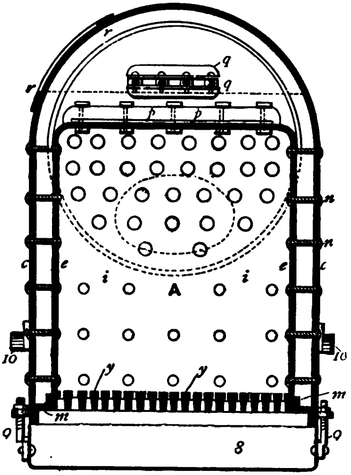

Fig. 61.—Scale: half-inch to a foot.

Portable engines are made up to 30 or even 35 nominal horse power, but boilers as large as that are slightly different in form, and are composed of many more plates than the one we have undertaken to describe.

The firebox shell is composed of three plates, namely, the front or *door-plate*, *a a*, Fig. 58, the *back-plate*, *b b*, and the saddle or *arch-plate, c c,* Figs. 58 and 61. The two former plates are flanged deeply all round to receive the rivets by which they are united to the arch-plate, and in addition the back-plate, *b b,* is flanged outwards for the reception of the barrel. These are all usually $\frac{3}{8}$ of an inch thick, and of B B Staffordshire boiler plate, or of equal quality. The barrel is formed of two $\frac{5}{16}$ inch B B plates, each bent round into a cylinder, and placed telescopically (or one inside the other) at the junction. The cross-section of the barrel at Fig. 60 shows the lap-joint, *d,* which is double-riveted, and the laps of the two rings are placed at opposite sides of the barrel to "break joint."

The smaller ring is flanged outwards at *e e,* Fig. 58, for the attachment of the *tube-plate, f f,* which, in its turn, is also flanged to fit the smokebox covering-plate, *g g,* Figs. 58 and 59.

The tube-plate is $\frac{5}{8}$ inch thick, and is pierced with a number of 3-inch holes for the tubes. The smokebox is completed by the insertion of a flanged *front-plate, h h,* Figs. 58 and 59, having a large hole cut out of it to be afterwards closed by a door. This plate, as well as the covering-plate, *g g,* is from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch thick.

The firebox is made wholly of Lowmoor or Yorkshire iron, and consists of three plates: the *tube-plate, i i,* Figs. 58 and 61, $\frac{5}{8}$ of an inch thick, flanged all round, except at the bottom, and pierced with $2\frac{3}{4}$-inch holes for the tubes; the *door-plate, j j,* Fig. 58, is flanged round like, *i i,* and outwards for the *door-hole,* to meet the solid wrought-iron ring, *k k,* which connects the inner and outer fireboxes together at this point.

The door-plate, as well as the *covering-plate, l l,* Figs.

58 and 61, are $\frac{3}{8}$ inch thick, the latter plate forming in one piece the two sides and roof of the firebox. The junction of the inner and outer fireboxes at the bottom is effected by the *foundation-ring*, *m m*, Figs. 58 and 61, which is a square wrought-iron frame of Z-section riveted all round to both boxes.

The tubes are of a superior quality of iron, lap-welded, and about $\frac{1}{8}$ inch thick. The usual diameter outside is $2\frac{3}{4}$ inches, but at the smokebox end the diameter is increased to 3 inches to allow of the tube being easily drawn out when encrusted with scale. Both ends are tightened in the tube-holes by the *expander*,* and at the firebox end steel rings, called *ferrules*, are tightly driven into the ends of the tubes with the double object of wedging them firmly into the holes and of protecting the tube itself from the direct action of the fire.

Staying.—The flat parts of the boiler, such as the sides and top of the firebox and shell, and the tube-plate at the end of the barrel are inherently weak in form, and unless strengthened by what may be called artificial means would become bulged and distorted at a fraction of the internal pressure they are called upon to sustain.

The cylindrical parts of the boiler, the barrel, and the upper part of the arch-plate, *c c*, on the contrary, need no extraneous support, and no amount of internal pressure short of that actually necessary to tear the plates asunder would cause any distortion.

The inner and outer fireboxes are tied together by *staybolts*, *n n*, Figs. 58, 59, and 61, which are simply short studs, having a screw thread cut upon them from end to end, and tightly screwed through *tapped* or threaded holes in both boxes. The ends are then cut off, leaving half an inch or so projecting at each end, which is afterwards riveted over cold. The pitch, or distance apart, of these stays is about 5 inches, and they are usually of $\frac{7}{8}$ inch diameter. The firehole ring *k k* also forms a very efficient connection at that point between the two boxes.

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* See p. 34, Chapter II.

The flat roof of the firebox is occasionally stayed to the top of the outer firebox in the manner just described, but for small boilers the all but universal practice is to use the *bridge-stays* shown at *p p*, Figs. 58 and 61. These, as will be seen, are flat bars riveted together in couples at about an inch apart, and resting upon their ends only at the edges of the firebox.

These form girders, and the roof-plate is hung up to them by strong bolts, having large square heads resting upon the bars and tightened up by nuts inside the firebox. To allow the free passage of water under these girders they are raised half an inch or so above the plate by distance-pieces or *washers* placed between. The tube-plate of the firebox is firmly stayed to the smokebox tube-plate by the tubes themselves, which are amply strong enough to afford these two flat surfaces mutual connection and support. Formerly it was the practice to insert several *stay-tubes*, as they were called, amongst the others. These were screwed at both ends and passed through both tube-plates, and secured by lock-nuts back and front, but for all ordinary pressures experience has demonstrated the ability of the ordinary tubes to do all that is needed.

The two ends of the boiler, the smokebox, tube-plate, and firebox front-plate, are connected above the tubes by four *stay-rods*, *o o*, Figs. 58, 60, and 61. A pair of *angle-irons*, *q q*, are riveted an inch and a half apart to each end of the boiler, and the stay-rods being formed with *eyes* at each end, pins are dropped through holes in the angle-irons and through the eyes in the rods.* To allow for differences of expansion between the boiler itself and the stay-rods, the eye-holes are made a little oval, so as to permit of some end movement.

Fittings.—For obtaining access to the inside of the boiler a large oval hole, *r r*, Figs. 58 and 61, about 14 inches by 11 inches, is cut out of the shell upon the left-hand side of the firebox, and to make up for the weakening effect of the hole the plate is strengthened by a broad flat ring riveted round the hole. The hole is closed by the *man-lid*, a heavy cast-iron plate, which can be introduced edgewise into the oval hole, and then turned round into position. A flange, or lip, all round, fits against the inside of the boiler, and the steam-joint is made by an india-rubber ring slipped upon it, and the whole is tightened up by studs in the man-lid, passing through two bridges. The whole arrangement is clearly shown in the Plates. In the centre of the man-lid is a large brass screw-plug, closing a hole by which the boiler may be filled with water. At each lower corner of the firebox there is an exactly similar oval hole, *s*, Figs. 58 and 59, but smaller, and without the protecting ring, closed in the same way, for cleaning out the water space. For the same purpose a brass screw-plug, *v*, Fig. 58, is placed at the lowest point of the smokebox tube-plate; and upon the roof-plate of the firebox, at *w*, Fig. 58, is another brass screw-plug, having a hole through it, filled with fusible metal, which is intended to give notice by melting when the water-level falls too low.

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* See p. 27, Chapter II.

The firebars, *y y*, Figs. 58 and 61, of cast-iron, having $\frac{1}{2}$ inch to $\frac{3}{4}$ inch air-spaces between, are supported by a pair of angle-irons, *x x*, Fig. 58, riveted to the back and front of the fire-box. At *z*, in the same figure, is shown a section of the firedoor of cast-iron, with a *baffle-plate* or deflector, 1, riveted to it. The door itself is perforated for the admission of air above the fire, and the inclination of the baffle-plate deflects the current upon the burning fuel.

The *smokebox-door*, 2, Fig. 58, is also fitted with a baffle-plate, but the object of this is only to preserve in some degree the door itself from the action of the hot gases. The baffle-plate is about $\frac{1}{4}$ inch, and the door $\frac{3}{16}$ inch in thickness. The hinge-joint and the catches are clearly shown in the figures.

A *chimney-base*, 3, Figs. 58 and 59, of cast-iron, having a square flange, by which it is affixed to the smokebox, forms the lower part of the chimney, and to this the chimney proper, by means of a cast-iron hinge-ring, *u*, is jointed. When the chimney is raised, a couple of bolts are passed through the two flanges to keep it in position. The top of the chimney is fitted with a *bell-mouth*, 5, and a *dome-top*, 6, to act as a spark-catcher, and occasionally, when the fuel to be used is wood or straw, the space between the two is covered round with a copper-wire network, in which case the dome-top is so arranged upon the end of a long rod, that by means of a lever worked from below it can be raised or lowered, as may be required, to suit the draught. The chimney is formed of two plates, lap-jointed together, and from $\frac{1}{8}$ to $\frac{3}{16}$ inch thick.

The ashpan, 8, Figs. 58, 59, and 61, is simply a shallow box of $\frac{3}{16}$ inch plate, held up to the bottom of the firebox by eye-bolts, 9, Figs. 58, 59, and 60, and having one side hinged so as to either admit or exclude the supply of air necessary for combustion, by which means the intensity of the fire may be regulated. A small chain, hitched to a hook, screwed into the firebox, serves to hold this *damper*, as it is called, in the required position.

An analysis of the proportions adopted by an eminent firm of manufacturers in the boilers of their portable engines is given in the following table.

It will be noticed that the allowance of heating-surface and of grate-area per nominal horse-power *decreases* gradually, and the ratios of tube-surface to firebox heating-surface and of total heating-surface to grate-area slowly *increase*, with the size of the boiler.

For burning wood or straw the fireboxes are made larger, so as to present about one-sixth more heating-surface than those given in the table, which are intended for coal burning. In calculating the heating-surface, the whole interior of the firebox (except the area of firedoor-hole and tube-holes) and the entire surface of the tubes are taken, and the flue-way, or united cross-sectional area of tubes, does not take into account the obstruction due to the ferrules at the firebox end.

From $2\frac{1}{2}$ to 6 horse-power the tubes are $2\frac{1}{2}$ inches external diameter, from 7 to 25 horse-power they are $2\frac{3}{4}$ inches, and in the 30 horse-power boiler they are 3 inches in diameter.

All these boilers are required to pass a cold-water test of 200 lbs. per square inch, and are intended to be regularly worked at 80 pounds steam-pressure.

PROPORTIONS OF PORTABLE-ENGINE BOILERS.

H.P.	HEATING SURFACE.					GRATE-AREA.			TUBES	H.P.
Nominal Horse-power.	In Firebox.	In Tubes.	Total.	Per Horse-power.	Ratio. Firebox surface to Tube surface.	Total.	Per Horse-power.	Ratio. Grate-area to Heating surface.	Flue-way or Area through Tubes.	Nominal Horse-power.
No.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	$\frac{1}{n}$	sq. ft.	sq.ft.	$\frac{1}{n}$	sq. ft.	No.
					n=			n=		
2½	11·0	44·0	55·0	22·0	4·0	2·2	·88	25·0	·39	2½
3	12·7	50·9	63·6	21·2	4·0	2·5	·83	25·5	·39	3
4	16·1	64·8	80·9	20·2	4·0	3·0	·75	27·0	·52	4
5	19·6	81·8	101·4	20·2	4·2	3·6	·72	28·2	·66	5
6	21·9	98·5	120·4	20·0	4·5	4·1	·68	29·4	·72	6
7	24·3	115·7	140·0	20·0	4·8	4·6	·66	30·3	·90	7
8	27·3	141·4	168·7	21·1	5·2	5·2	·65	32·1	1·02	8
9	29·7	148·6	178·4	19·8	5·0	5·8	·65	30·4	1·02	9
10	32·4	161·9	194·3	19·4	5·0	6·2	·62	31·1	1·08	10
12	36·0	183·4	219·4	18·3	5·1	7·1	·59	31·3	1·15	12
14	40·5	205·2	245·7	17·5	5·0	7·8	·55	31·5	1·26	14
16	43·0	228·7	271·7	16·9	5·3	8·6	·53	31·6	1·39	16
18	48·2	255·3	303·5	16·7	5·3	9·6	·53	31·6	1·60	18
20	53·0	279·2	332·2	16·6	5·3	10·5	·52	31·7	1·60	20
25	59·3	346·5	405·8	16·0	5·8	12·8	·51	31.8	1·87	25
30	68·1	408·8	476·9	15·9	6·0	14·9	·49	31·9	2·35	30

THE WHEELS, AXLES, AND UNDER-CARRIAGE.

We have now to consider the last of the three principal divisions of the Portable Engine, namely, the means by which it is rendered actually portable or movable.

The entire engine and boiler are carried by four wheels, the front pair of which are capable of swivelling laterally round a centre, for the purpose of easily turning corners, exactly as in a common waggon.

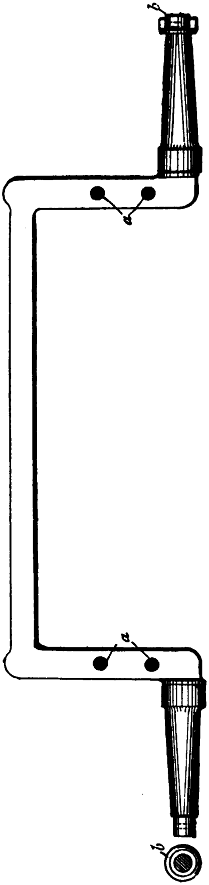


Fig. 62.—Hind Axle. Scale: three-quarters of an inch to a foot.

Fig. 62 shows the *hind axle*, which is attached to the firebox shell by a pair of lugs shown in the views of the boiler at 10, Figs. 58, 59, and 61. (In the general drawings the axle is shown in place.) A thin piece of hard wood is inserted between the axle and the lug to check vibration, and possible fracture of the bolts in the holes *a a*, by which it is secured. The *arms*, or ends of the axle are taper, and are case-hardened to resist wear. To keep the wheels in place, a collar, shown at *b b*, is driven upon the short parallel part at the end of the arm, and secured by a pin passing through it. The size of the square bar from which the axles are made would vary from about two inches square for the $2\frac{1}{2}$-horse engine, to four inches for the 30 horse-power engine.

Referring again to Fig. 63, which represents the front wheels and *fore-carriage*, it will be seen that a cast-iron *turnplate*, *a*, convex at the bottom, is riveted to the under side of the boiler barrel. Another casting, *b*, with a corresponding concavity in its upper surface, is firmly attached to the front axle *c c*, and the whole

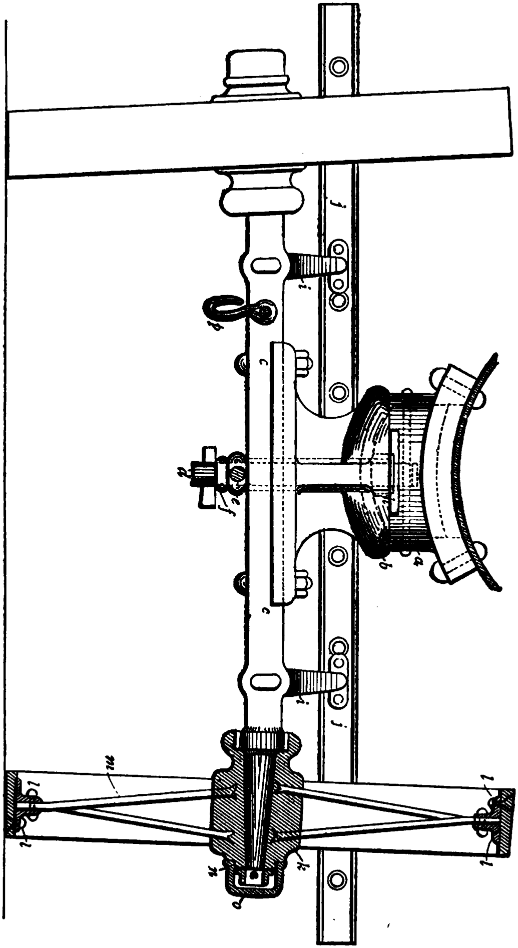


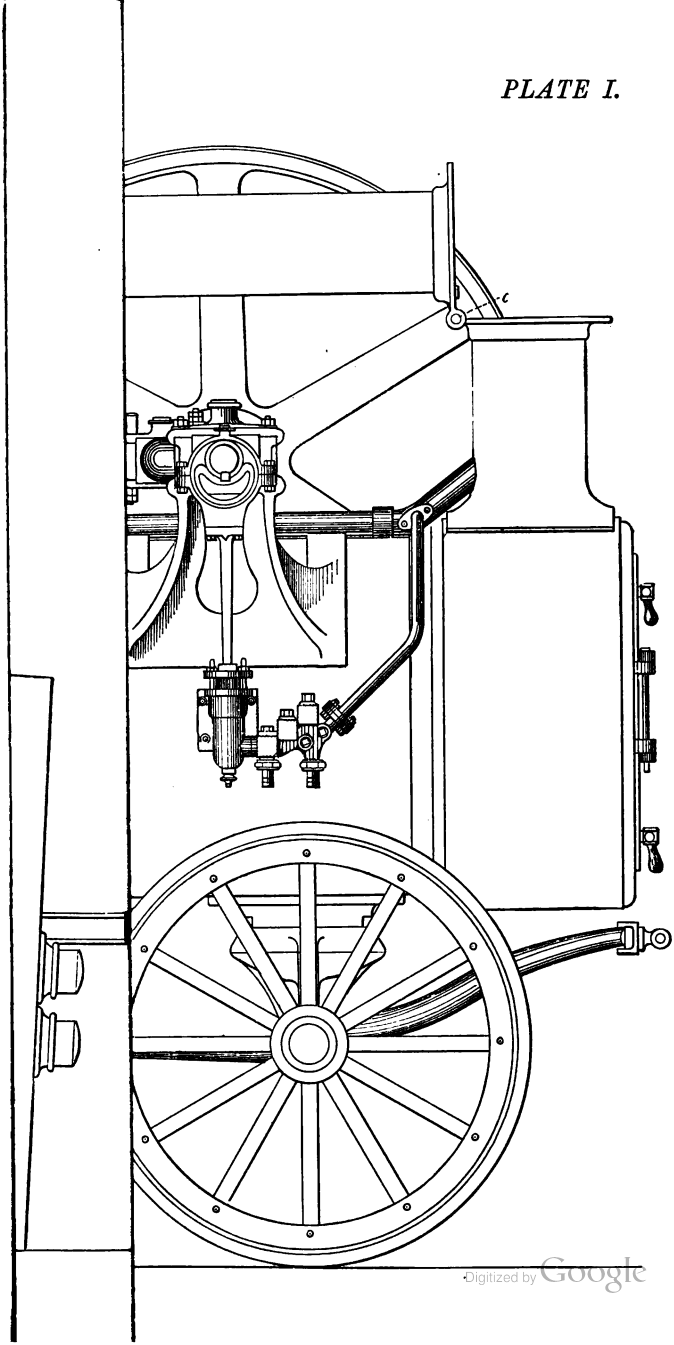
Fig. 63.—Front Wheels and Fore Carriage. Scale: three-quarters of an inch to a foot.

arrangement is kept together by the *main-pin, d.* To allow of swivelling and rolling movement in the lower turn-plate and axle, the hole through which the pin passes is made oval in section, as indicated. At *e* is shown the eye, or end of the *main-stay*, which there encircles the lower part of the pin, and will be seen in the general drawing (side elevation), extending from this pin to the back of the firebox, where another eye, 12, Fig. 58, is inserted to receive it. *f*, Fig. 63, is a ring attached to the chain of the *slipper*, or drag, slipped over the main-pin above the cotter *g*, and seen hanging from it, in Plate I. (Fig. 2).

At *h* is shown one of a pair of *snugs* or projections cast upon the upper turnplate, fitting in corresponding recesses in the lower one, by which the lateral swivelling of the axle is limited; *i i* are a pair of strong wrought-iron arms, riveted into the axle, which is swelled to receive them, for carrying the *splinter-bar j j*, a strong bar of [-section, to which they are riveted at their upper ends. These are fully shown in Plate I. (Fig. 2), (side elevation), which also shows clearly the *eyes* and *pins* for the attachment of a pair of *shafts* for horses. A section of one of the fore-wheels, showing the detail of the cast-iron *boss*, *k*, is given at Fig. 63, which, combined with the side elevations of both fore and hind wheels, given in Plate I. (Fig. 2), should convey a clear idea of their construction, which may be described thus (premising that except in diameter and number of spokes the four wheels are all exactly similar) :—

The ends of the spokes, which are coated with tin, are laid radially in the mould for the boss. A steel *chill*, or plug, exactly like one of the axle-arms, is also laid in the centre of the mould, to form the *core* for the hole in the boss. The casting is then made, and the

PLATE I.



the angle A O B is in excess of a right angle, is called the *angular advance.*

As now arranged, our engine is constructed to take steam at the moment the crank is passing the *dead centre,* or, in other words, when the position is at either end of its stroke. But the piston, crosshead, and connecting-rod are heavy, and the sudden reversal of the motion of these parts, some two hundred and fifty times a minute, produces undesirable shocks and strains in the engine; so much so as to suggest the employment of some kind of spring or buffer at each end of the cylinder to take up the momentum of the

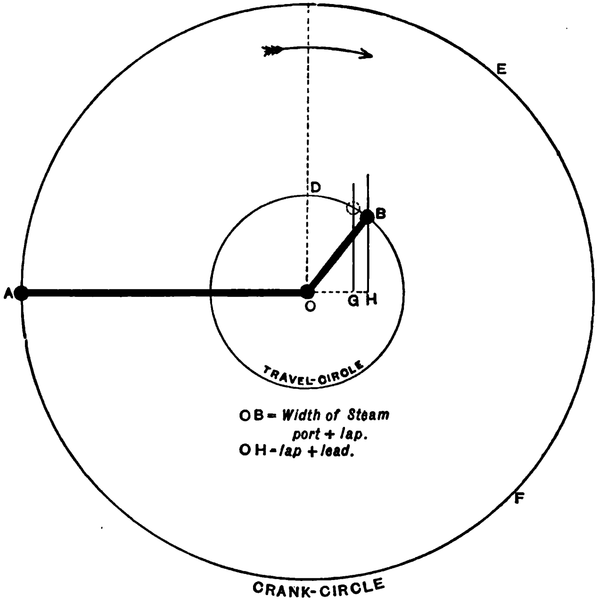
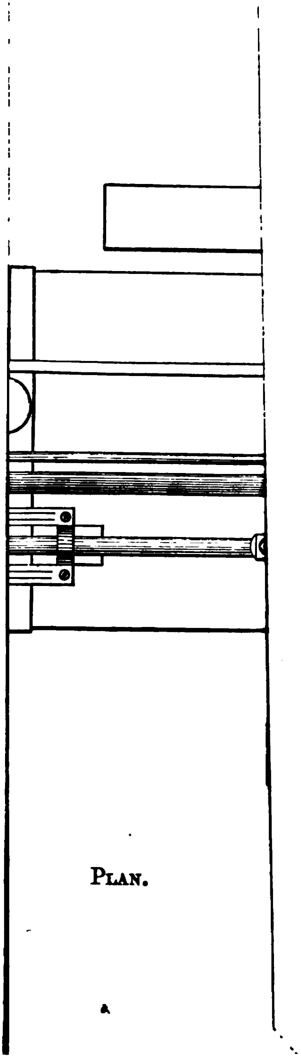


Fig. 67.—Diagram of Crank and Excentric, with lap and lead.

ENGINE CON



PLAN.

retaining the same travel; or it will take place *later* if these conditions be reversed. In each case the eccentric must be set so as to give the proper lead.

A useful formula for finding the point of cut-off, having the lap, lead, and travel given, is the following:—*

Let L = the lap;
,, l = the lead;
,, S = the stroke of piston;
,, T = the travel of the valve;
and x = the distance travelled by the piston before steam is cut off:

$$\text{Then } x = S\left[1-\left(\frac{2L+l}{T}\right)_2\right]$$

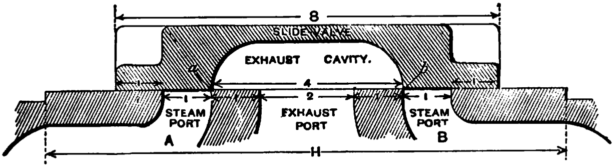


Fig. 68.—Section of Slide-valve and Cylinder Face.

Or, having the point of cut-off required and the lead and travel, to find the *lap:*

$$L=\left(\tfrac{1}{2}\,T\sqrt{\frac{S-x}{S}}\right)-\tfrac{1}{2}\,l.$$

By way of example we may apply this rule to the present case, taking the stroke of the engine as 12 inches and the lap as 1 inch, with lead and travel in the proportions indicated. The travel will then be 4 inches and the lead $\frac{1}{12}$ inch, or ·0833 inch.

$$= 12\left[1-\left(\frac{2\cdot0833}{4}\right)^2\right] = 8\cdot75 \text{ inches, or 73 per cent.}$$

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* From Molesworth's Pocket Book.

We now know, in the first place, that certain advantages result from an early cut-off of the steam in the cylinder; and secondly, that by giving *lap* to the slide-valve in a certain proportion to its travel, any desired cut-off point may be secured.* We have the means (by the formulas just given) of determining what the lap should be for any required cut-off, and by the formula on page 91 we can ascertain (the initial pressure being given) what effective pressure will be exerted upon the piston either at any given point or during the whole stroke.

A German engineer, Professor Zeuner, has given us, however, a most ingenious and beautiful method of graphically placing before the eye the whole cycle of operations performed by the slide-valve in one revolution; and it is difficult to say whether the Zeuner *valve-diagram*, as it is called, excels in ease of construction or in the fidelity with which it indicates what the valve is doing at any part of the stroke. Nay, more, we have only to say at what part of the revolution we wish cut-off, exhaust opening or closing, lead or compression, to take place, and in a few minutes we can construct a diagram from which all the details of a slide-valve to fulfil the conditions can be measured off, and the whole movement criticised from first to last, with as much certainty as though we saw the valve at work in the completed engine.

The diagram is constructed as follows for an ordinary single slide-valve. A line, A B, Fig. 69, representing to any convenient scale the stroke of the piston, is drawn as the diameter of a circle representing the path of the crank-pin, called the CRANK-CIRCLE. From the same centre is struck a smaller circle showing the path of the centre of the excentric sheave. This is usually drawn full size, but for the sake of keeping this and succeeding diagrams within reasonable limits of size, we shall suppose our valve and cylinder-face to be of

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* The ordinary slide-valve is not adapted for cutting off *earlier* than half-stroke, however.

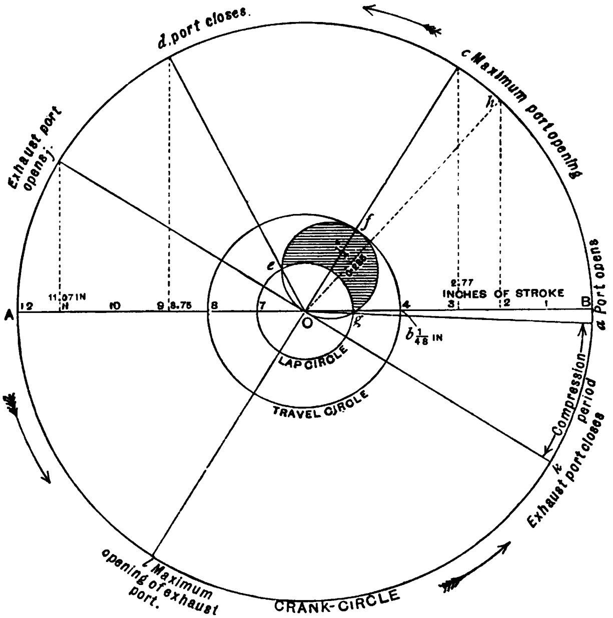

Fig. 69.—Zeuner Diagram.

the actual size of those in Fig. 68, and take $\frac{1}{4}$ inch as the unit. The travel of the valve being four times the unit, or 1 inch, this will be the diameter of the TRAVEL-CIRCLE. From the same centre, O, is struck with a radius equal to the lap (viz. $\frac{1}{4}$ inch), the LAP-CIRCLE.

The crank is supposed to start from the point B, and to run in the direction of the arrows, A and B being thus the *dead-centres,* or points in the revolution at which the piston is at the extremities of its stroke.

Lead, or pre-admission, begins, it will be remembered, *before* the crank arrives at the dead-centre B, and the port is to be open $\frac{1}{12}$th of the unit, or $\frac{1}{48}$ inch, when the crank gets to that point. To represent the lead, then, we draw the line O *a,* cutting the travel-circle at *b,* $\frac{1}{48}$ inch below the centre line A B, and the point *a* upon the crank-circle denotes the exact spot in the revolution of the crank at which steam-admission begins.

Cutting this line O *a* at *g* upon the lap-circle, and passing through the centre O, a fourth circle, *e f g,* is described whose radius equals one-half that of the travel-circle. As explained upon page 95 the radius of the excentric equals the lap and the port-opening together. The shaded portion of the circle *e f g,* therefore, exterior to the lap-circle *represents port-opening.* The two extremities of this crescent-shaped portion mark the points of opening and closure of the port respectively. As the radius O *a* gives the opening, so the radius O *d* drawn through the other intersection of the lap-circle with the circle *e f g* gives at *d* the point where the valve closes the port and cuts off the steam. The radius O *c* passing through the centre of the circle *e f g* points to the maximum port-opening, $\frac{1}{4}$ inch, and throughout the arc of steam admission, *a c d,* the amount of port-opening for any position of the crank always equals the width of the shaded crescent at the corresponding radius. For example, the port-opening, when the crank is at the point *h*, is measured along the radius O *h*, and at that point equals ·235 inch.

The line A B, representing the stroke of the piston, may be conveniently divided into equal parts representing inches of stroke. In this case it is divided into twelve parts, and a perpendicular let fall from the point *d*, where the cut-off takes place, cuts the line A B at a point 8·75 of these inches from the beginning of the stroke, thus confirming the correctness of the formula given on page 98. A similar perpendicular from *h* shows that at two inches of the stroke the valve had uncovered the port to an extent of ·235 inch. So the action of the valve, as it covers and uncloses the ports, can be closely followed throughout the stroke. As there is no exhaust lap (*i.e.* the inner edges of the exhaust cavity *a* and *b*, Fig. 68, *coincide* with those of the ports when the valve is at mid-travel), the point of exhaust opening, *j*, is distant just one-fourth of the circle, or 90° from the maximum steam-port opening *c*, or at 11·07 inches of stroke. The exhaust remains open for half the revolution, attaining its maximum at *l*, a point diametrically opposite to *c*, and closes at *k*, from which point the steam yet remaining at atmospheric pressure in the cylinder is (as we shall see when considering the Indicator diagram) gradually compressed by the advance of the piston to nearly boiler pressure, and prepares the way for the admission at *a* of steam for a new stroke.

The portion of the revolution from *k* to *a* is called the *compression period.*

Thus the crank has performed, under our scrutiny, an entire revolution, but only so far as one end of the cylinder is concerned.* The points of cut-off and release differ slightly for the two ends of the cylinder on account of the angularity of the connecting-rod, as will be explained presently. The diagram, however, indicates correctly the *mean* cut-off.

One more point may be noticed here. Temporarily assuming that the engine runs in the direction *contrary* to the arrows, and that the crank-radius is lying at A O, then the angle A O *c* gives the correct position of the excentric (whose centre would be at *f*) relatively with the crank.

In our consideration of the diagrams we have assumed certain proportions for the valve, and constructed the diagram accordingly; but it is obvious that this procedure might be reversed and the proportions of the valve or the travel found by construction from a given cut-off and admission, laid down as points in the revolution.

Exhaust Lap.—To illustrate the nature of the influence exercised by exhaust lap upon the release and compression of the steam, we give another example of a slide-valve and its Zeuner diagram. The question of its desirability or otherwise will receive attention when we come to the consideration of the Indicator diagram.

Fig. 70 shows a slide-valve and cylinder face, exactly similar in all respects to that illustrated by Fig. 68, save that *lap* to the extent of $\frac{1}{16}$ inch, or $\frac{1}{4}$th of the unit, has been added to the inner edges of the exhaust cavity.

The exhaust lap appears on the diagram in the form of a small circle struck from the general centre o, whose radius, $\frac{1}{16}$ inch, equals the lap. From the point s is struck another circle, *p q r*, equal and opposite to the circle *e f g*,* and through the two points *u*

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* A *complete* diagram, showing both ends of the cylinder, and corrected for the angularity of the connecting-rod, is given at page 108 (Fig. 73).

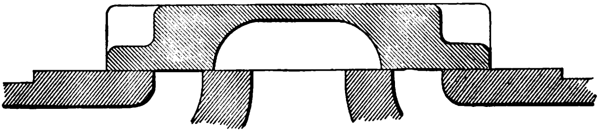

Fig. 70.—Slide-valve with Exhaust Lap.

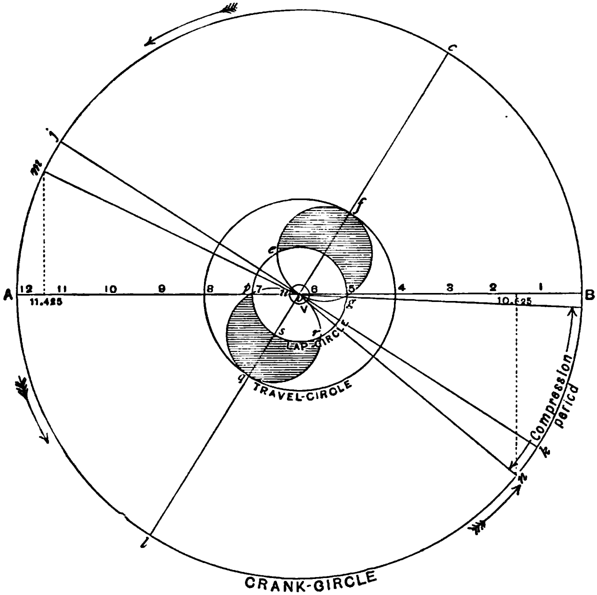

Fig. 71.—Zeuner Diagram for Exhaust Lap.

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* This circle is the one which would be drawn to show the port opening for the return stroke in the same way as the circle *e f g* was used for the out-stroke.

and *v*, where the former cuts the little exhaust-lap circle, are drawn the radii *m* o, *n* o. The point *m* in the crank-circle marks the opening of the exhaust, 11·425 inches from the beginning of the stroke, and *n* represents the closing-point, distant $10\frac{5}{8}$ inches from the beginning of the return-stroke. It will be observed that the effect of lap is to retard the opening and accelerate the closing of the exhaust port, and to prolong the period of compression, which has been increased from about $8\frac{1}{2}$ per cent. of the revolution to 14 per cent. The points *j* and *k*, which are the same as laid down upon the previous diagram, indicate the amount of alteration. Where so comparatively small a circle as that used here to denote the exhaust lap is required, it is desirable to construct the entire diagram upon as large a scale as possible, even three or four times the full size, as the exact points of intersection are rendered much clearer.

We have now seen how a Zeuner diagram is made useful in tracing out step by step the movements of the valve in relation to the crank, and how by its aid a slide-valve may be constructed which shall perform certain operations at given periods.

The diagram may be extended to show the action of the link-motion reversing gear, of various forms of expansion gear, with or without separate expansion or *cut-off* valves, and of almost every possible form or modification of apparatus applied to steam-engines, for the inlet and release of steam. But it is not our purpose to follow it further, or to enter into tho geometrical reasoning which underlies the application of this form of valve diagram. The reader who desires to follow up this most interesting study will find in the "Treatise" of Professor Zeuner,* or in Mr. Cowling Welch's book, "Designing Valve-gearing," † the subject dealt with at length, and its various applications exhaustively discussed. A very lucid explanation of the Zeuner diagram is also given in the chapter on Slide-valves in Mr. Arthur Rigg's treatise on the "Steam Engine." ‡

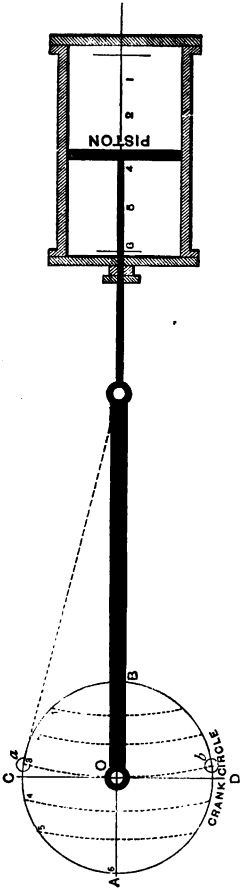

Fig. 72.—Diagram showing Irregularity induced by Angularity of Connecting-rod.

Disturbing Influence of the Connecting-rod. — Hitherto we have assumed, as in the diagrams Figs. 69 and 71, that the correct position of the piston for successive points in the revolution is always represented by an ordinate drawn from any point in the crank-circle perpendicular to the line A B. Thus, in Fig. 69 we have taken it for granted that at *h* the piston has moved two inches, $8\frac{3}{4}$ inches when the crank reached *d*, and 11·07 inches at *j*. Were the connecting-rod of infinite length this assumption would be correct. Connecting-rods in practice, however, seldom reach more than six or

* Klein's translation. Spon, 1884. † Spon. ‡ Spon.

seven times the length of the crank-radius, and an irregularity is thus introduced into the motion of the piston, to which we must devote a little space. In the skeleton diagram opposite, Fig. 72, the connecting-rod, represented by a thick line, is supposed to be uncoupled from the crank and lying in a straight line with the piston-rod. The piston is in the middle of its stroke, and the connecting-rod just reaches the centre of the crank-shaft O. If now the rod be raised or lowered to the positions *a* or *b* upon the crank-circle without moving the piston, it will be seen that the dotted arc *a* O *b*, described by the connecting-rod, cuts the crank-circle into two unequal divisions, consequently that the centre of the piston's stroke does *not* coincide with the mid-positions of the crank, denoted by the perpendicular line C D passing through the centre O. Points in the crank-circle corresponding to equal divisions in the stroke of the piston, as 1 2 3 4 and 5, Fig. 72, are, however, correctly transferred to the line A B, when, instead of straight ordinates, *arcs*, with the connecting-rod length as a radius, are employed.

The Zeuner diagram, Fig. 73, is a reproduction of Fig. 69, save that the straight ordinates are replaced by arcs struck with a radius, representing the connecting-rod, of seven times the length of the crank,* and that the diagram is doubled, to show the return stroke, in order that the unequal points of cut-off, caused by the obliquity of the connecting-rod, may be clearly indicated.

The difference between the points of cut-off, viz.

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* The length of the connecting-rod in Fig. 72 is purposely reduced to four times the crank radius length in order to somewhat exaggerate the disturbing effect.

9·1 inches for the outward stroke, and 8·4 inches for the return, is now clearly shown.

The previous diagram, Fig. 69, with straight ordinates, gives the *mean* of these two measurements, or 8·75 inches, and similarly the piston, when the crank is at the two points *j* and *k*, is now shown to be

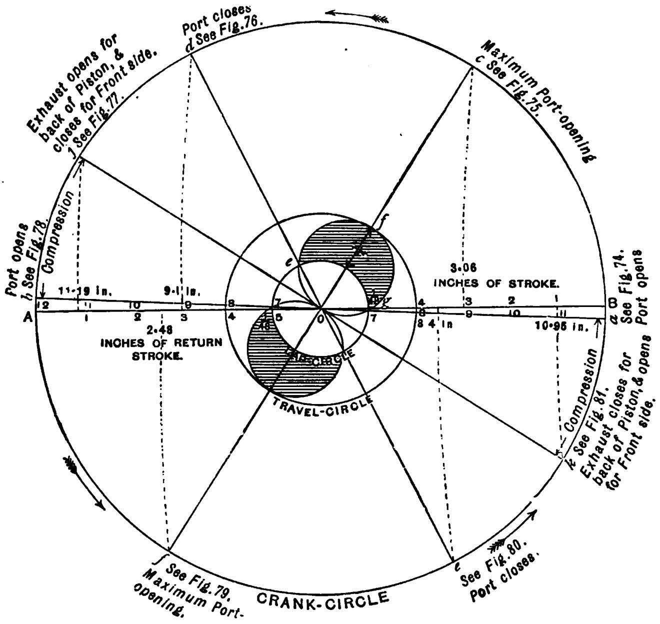

Fig. 73.—Zeuner Diagram, corrected for Error of Connecting-rod.

distant from the corresponding ends of the cylinder 11·19 inches and 10·95 inches respectively, the *mean* of these two measurements being that given upon the former diagram, 11·07 inches.

As this diagram, Fig. 73, represents what is going on upon both sides of the piston simultaneously, it would perhaps be advisable once more to follow the crank round the circle very briefly. The various positions of piston and slide-valve corresponding to the points in the crank-circle B *c d j*, &c., are also shown in the series of sections given below, Figs. 74 to 81.

At B in the diagram (see Fig. 74) the crank is on the dead-centre, ready to begin its stroke. Steam is already being admitted *behind* the piston, the port being open $\frac{1}{48}$ inch, and the front side is open to the atmosphere. With the crank at *c* in the diagram the maximum port-opening, $\frac{1}{4}$ inch, is reached (see Fig. 75), with the piston at 3·06 inches from its starting point.

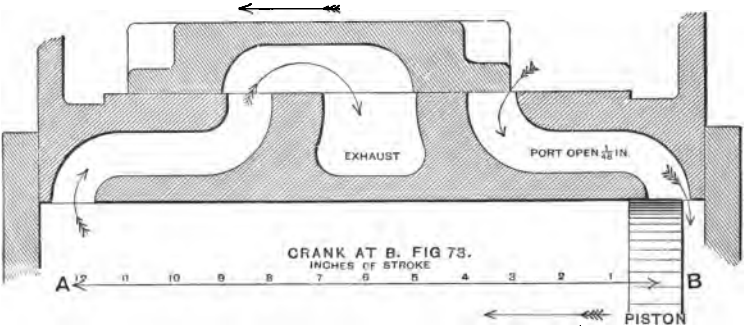

Fig. 74.—Slide-valve Section.

Steam continues on until the point *d* is reached by the crank, when the valve closes, and the period of expansion begins with the piston at 9·1 inch of its stroke (Fig. 76). All this time the *front* side of the piston has been in free communication with the atmosphere, but at the point *j*, in the crank-circle, the slide-valve closes the exhaust port for the *front* of the piston, and opens it to the back (Fig. 77), releasing the

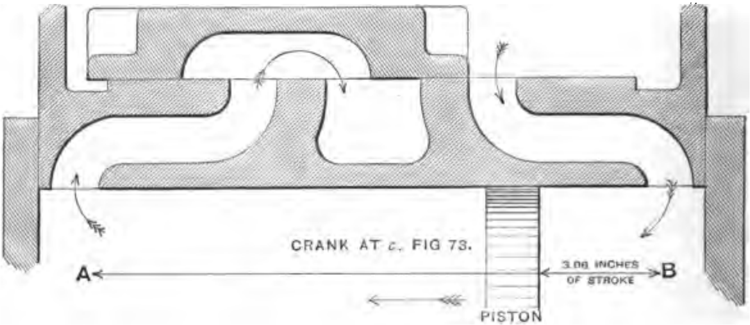

Fig. 75.—Slide-valve Section.

expanded steam (and remaining open until the point *k* is reached half a revolution later). This occurs at

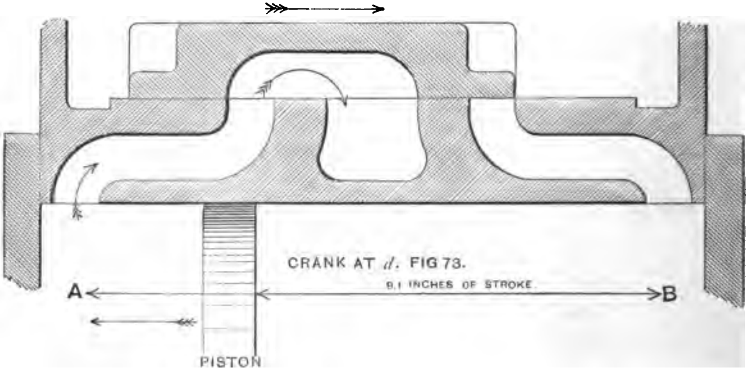

Fig. 76.—Slide-valve Section.

11·19 inches of the piston's stroke. The period of *compression* now begins for the front end of the cylinder, (supposed to have been filled with steam before our

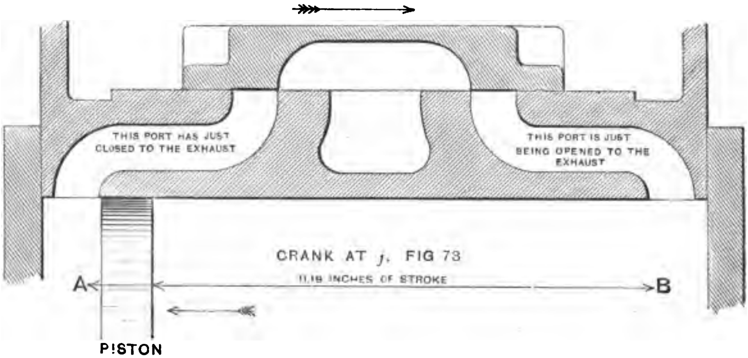
THIS PORT HAS JUST CLOSED TO THE EXHAUST
THIS PORT IS JUST BEING OPENED TO THE EXHAUST
CRANK AT j. FIG 73
11.19 INCHES OF STROKE
A
B
PISTON

Fig. 77.—Slide valve-Section.

illustrative stroke commenced), and this continues until the crank reaches the point A in the diagram

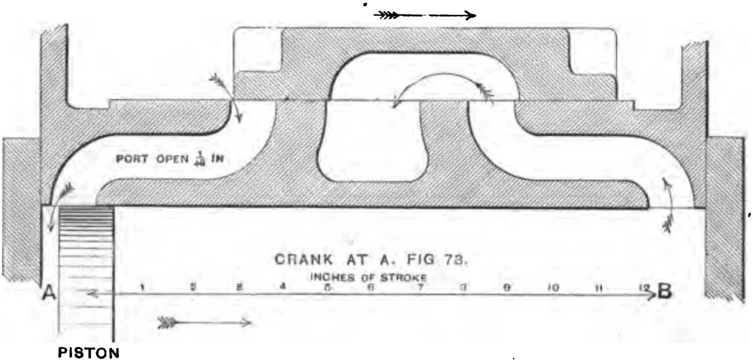

Fig. 78.—Slide-valve Section.

(see Fig. 78). At A the port opens to the boiler, and *admission* begins. The maximum opening is reached at *f* in the crank-circle (Fig. 79), with the piston 2·48 inches upon its return stroke.

At *e* in the diagram the port closes (Fig. 80) at 8·4 inches of piston, the steam expanding until the point *k* is reached 10·95 inches from the beginning of the stroke, where release begins (Fig. 81), and continues for half the revolution. At *k* also the valve regains its central

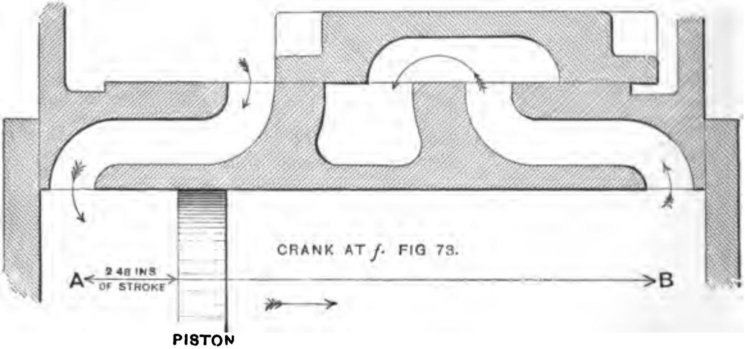

Fig. 79.—Slide-valve Section.

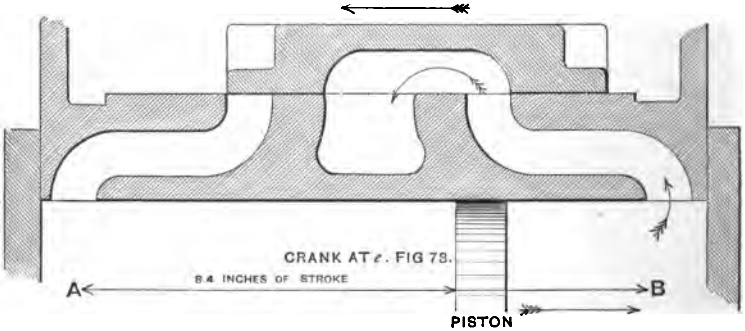

Fig. 80.—Slide valve Section.

position, the exhaust closes for the *back* end of the cylinder, and compression of the small quantity of steam left in the cylinder takes place, until fresh steam from the boiler is admitted at *a*, and the cycle of operations goes on again, and continues as long as steam is supplied to the engine.

Referring for a moment to the diagram, Fig. 73, it will be noticed that, as there is no exhaust lap, each end of the cylinder in turn remains open to the exhaust for half the revolution, and the valve closes for the one and opens for the other at the same instant.

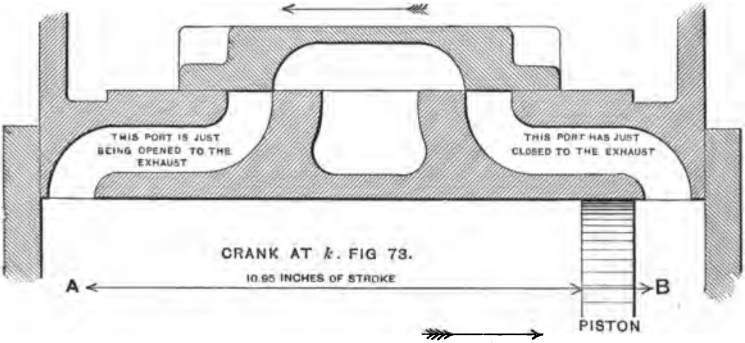
THIS PORT IS JUST BEING OPENED TO THE EXHAUST
THIS PORT HAS JUST CLOSED TO THE EXHAUST
CRANK AT *k*. FIG 73.
10.95 INCHES OF STROKE
A
B
PISTON

Fig. 81.—Slide-valve Section.

Variable Expansion by Means of an Adjustable Excentric.—Hitherto we have considered only the action of an excentric having a fixed travel, and consequently an invariable cut-off point. In an earlier chapter* we have described the construction of a *movable* excentric sheave, capable of being clamped in several different positions against a fixed *expansion-plate*, or disc, having a curved slot formed in it by which the position of the sheave is determined.

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* Chap. III., pp. 60-61.

An inspection of the diagram of such an excentric, Fig. 82, will show, by the circles drawn cutting the lap-circle at points representing the different fractions of the stroke during which steam is to be admitted, that the centre of the excentric sheave has only to be moved given distances in a straight line, from *c*, which is the maximum cut-off, to *b*, where the admission is for only $\frac{3}{8}$ths, to secure the closing of the port at those or any intermediate fraction of the stroke. The diagram, which is drawn double the size of the preceding ones, for the sake of clearness, is thus constructed.

The fractions of the stroke measured along the line A B are transferred by ordinates to points in the crank-circle C D E F, and radii are drawn from these points to the centre O. The amount of pre-admission or *lead*, $\frac{1}{24}$ inch, being measured upon the travel-circle as before, the radius O *a* is drawn through it, and the angles C O *a*, D O *a*, E O *a*, and F O *a*, are bisected. Circles drawn upon these bisecting lines C′ D′ E′ F′, cutting the lap-circle at the radii C D, &c., and at the constant lead-point *l*, give by their diameters the four points representing *c d e f*, the position of the centre of the excentric sheave when set to cut-off at the different fractions of the stroke, the crank being supposed at A.

The darkly shaded crescent shows the port-opening for the three-eighths cut off, the lighter one that for the maximum, the intermediate circles the openings for the half and five-eighths respectively. The four points *c d e f* are situated in a straight line drawn at right angles with the lead radius O *a*. For reversing the engine similar points, *c′ d′ e′* and *f′*, may be found upon the other side of the centre line, and the shape of the slot in the expansion-plate, by which the excentric sheave is guided, is shown by the dotted lines outside

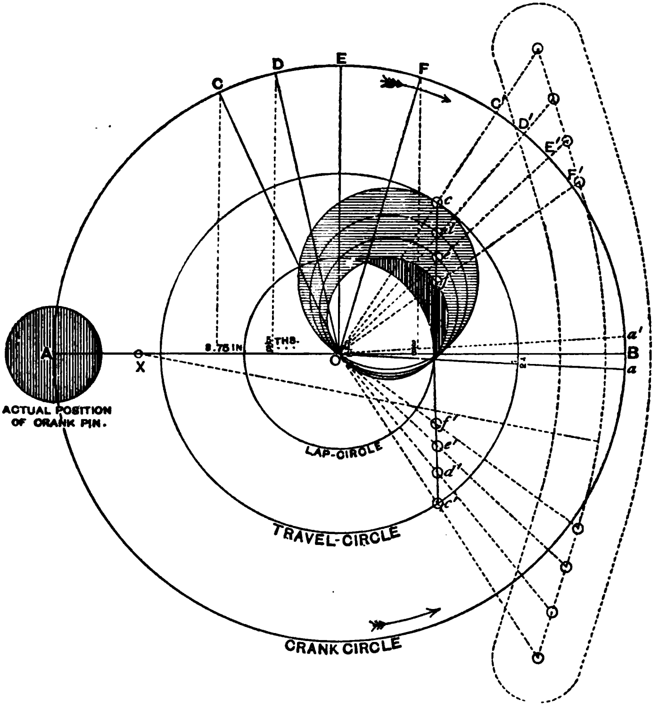

Fig. 82.—Zeuner Diagram for Variable Expansion.

the crank circle. As will be seen, the slot is formed by equal prolongations of the radii C′ D′ E′ F′ from the points *c d e f*, the two ends being connected by an arc struck from the centre X.

The radii giving the points for opening and closing the exhaust are not shown in the diagram, to prevent confusion, but they may be drawn in at right angles with the centre lines C′ D′ E′ F′ for each position.

It will be seen that the earlier the cut-off the earlier also is the closing of the exhaust, and at three-eighths of the stroke there is rather an excessive amount of compression. In engines constructed for working with a high degree of expansion an arrangement of double slide-valve is used, by which the cut-off point can be reduced without affecting the freedom of the exhaust.

CHAPTER VI.

THE INDICATOR DIAGRAM.

REFERRING to page 90, we find a table of pressures within the cylinder for successive points in the stroke, with the steam cut off at one-half, constructed upon the assumption that the pressures vary inversely as the volumes, which, though not absolutely true, is very nearly so. The variations in pressure may be exhibited graphically thus :—

The vertical divisions represent points in the stroke of the piston, and the horizontal lines stand for steam pressure in pounds per square inch. The thick dotted line represents the pressure in the cylinder.

For the first six inches it stands at a uniform pressure of 55 lbs. per square inch. At the sixth inch the steam is shut off, and the curved line shows that the pressure is rapidly falling as the piston moves onwards. The curve cuts the vertical line representing the seventh inch at a point almost midway as to height between the 45-lb. and 50-lb. divisions. The scale of pressure is 30 lbs. to the inch, and if measured, the actual height of the seventh ordinate would be found to be 47·14 lbs. At the 8 and 9-inch perpendiculars the measurements are 41¼ and 36⅔ lbs. respectively, and at the twelfth

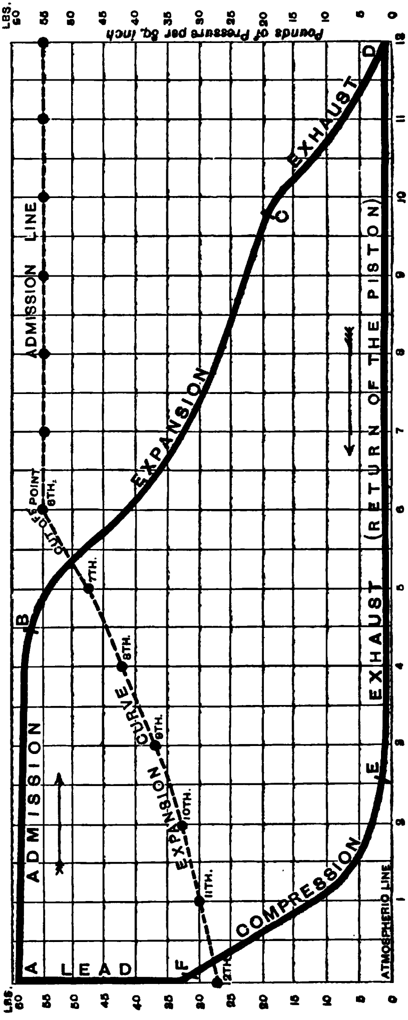

Fig. 83.—Indicator Diagram.

inch the curve has fallen to 27½ lbs., or half the initial pressure.

The diagram, read in this manner, gives exactly the same information as the table upon page 90, with the additional advantage that the pressure can be measured every half or quarter inch if desired. It is in this way that the pencil of the indicator records upon a card the rise and fall of pressure in the cylinder. The indicator is the stethoscope of the engineer, and just as by the aid of the Zeuner diagram he is enabled to design a slide-valve calculated to produce in the cylinder of his engine certain effects of expansion or compression, so by the indicator diagram he sees, traced by the invisible steam itself, a record which to the initiated eye reveals in minutest detail the faults or excellences of the apparatus he has constructed.

Before the adaptation of this instrument to high-speed engines, it is no figure of speech to say that we were completely in the dark as to the real behaviour of the steam in the cylinder. For instance, until the indicator enabled us to see that at high speeds pressure could not be maintained behind a piston unless the passages were large enough to allow the steam to get in and out quickly, we were without any reliable information as to proper proportions of steam-ports, and the importance of a free exhaust was more or less overlooked.

The diagram distinguished by a thick line in Fig. 83 is a copy of one taken from a portable engine cutting off at ⅜ths of the stroke, and we propose to follow the line (which refers only to one end of the cylinder) through a complete revolution. As we have already seen while investigating the action of the slide-valve, the stroke (for each side of the piston separately) is divided into four periods: admission, expansion, exhaust, and compression. These are all distinctly indicated by the diagram before us. The piston is supposed to be moving from left to right, and at the point A the steam pressure behind it reaches to 59 lbs. upon the square inch, and this is maintained at nearly a constant height until the point B, 4½ inches from the beginning of the stroke, is reached, when the period of admission ceases. It will be noticed that the point of cut-off is not nearly so sharply defined, on account of the gradual closing of the valve, in the *real* diagram as in the purely theoretical one to the right hand. From A to B is the line of *admission*, and from B to C is the line of expansion, approximating to the hyperbolic curve. At C, about 9¾ inches from the commencement of the stroke, the exhaust begins to open, and the released steam escapes from the cylinder during the remaining portion of the piston's travel, the rapidly declining pressure being denoted by the short curve C D. At this point the return stroke begins, and while the piston, urged by a new admission of steam upon the other side, re-traverses the distance D E, the exhaust port remains open, and the pressure in the cylinder reduced to that of the atmosphere (indicated by the exhaust line D E), coincides with the zero point of the scale. The cylinder, however, still contains steam at atmospheric pressure, and after the piston passes the point E, which marks the closing of the exhaust port, this latent steam undergoes *compression* for the remainder of the back stroke. From E to F the pressure of this entrapped steam rises gradually to about 32 lbs., and finally at F *pre-admission*, or lead, begins, and during the last quarter of an inch or so of the stroke the pressure rises abruptly to 60 lbs., in readiness for the beginning of a new stroke at A. At first sight it would appear that compression, which is a pressure *against* the advance of the piston, would result in a loss of power. This is not the case, however, as the piston recoils with exactly equal force, and the elastic steam cushion is most useful both in taking up the momentum of the reciprocating parts of the engine, at the changes of direction which occur at the ends of the stroke, and in gradually leading up to the pressure of the steam admitted for the beginning of the next stroke, which, striking the piston in an empty cylinder some hundreds of times per minute, would speedily hammer the engine to pieces. In locomotive engines, which sometimes attain an enormous piston speed, an extraordinary amount of compression induced by the early cut-off employed is

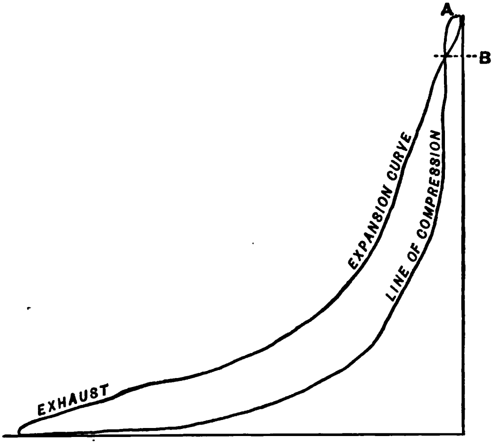

Fig. 84.—Indicator Diagram, showing effect of Excessive Compression.

found to be in no way injurious, but, on the contrary, highly beneficial.

In some cases this is carried to such an extent that the steam remaining in the cylinder is compressed to above boiler-pressure, and a *fall* takes place when the port is opened. This is illustrated by Fig. 84. Upon the return stroke the pressure rises to the point A, but falls to B directly the port opens, the excess of pressure being discharged into the boiler. This is always indicated by a loop in the corner of the diagram.

Fig. 85 shows the effect of insufficient passage-area, or port opening. This particular defect is known as *wire-drawing*, and is caused by the inability of the steam to make its way into the cylinder fast enough to maintain the initial pressure behind the rapidly advancing piston. The pressure, it will be observed, has fallen to such a degree that it is hardly possible to distinguish where the admission line ends and the expansion curve begins. Another defect is illustrated in the same diagram, namely, *late admission*. There is no compression, and the admission of steam is so gradual that the piston has travelled some distance before the full pressure is arrived at.

Back pressure is also shown by the exhaust-line being a pound or two above the atmospheric line. The late admission in the engine, from which this diagram was taken, could be easily cured by simply moving the excentric round upon the shaft, giving it more *angular advance :* the exhaust would then be opened and closed earlier in the stroke than at present, and any desired amount of compression and pre-admission might be obtained, but the wire-drawing can only be obviated by removing the obstruction in the steam passage.

Portable engines, controlled by a throttle-valve acted upon by a governor, are generally conspicuous examples

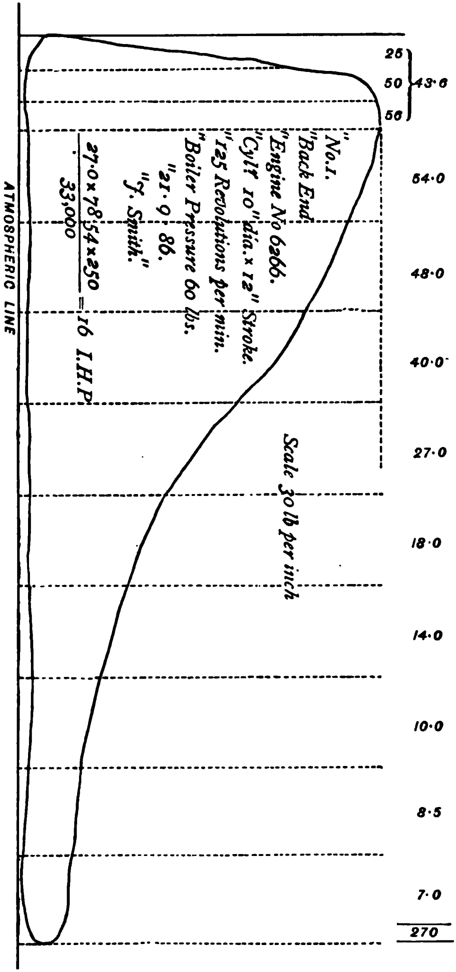

Fig. 85.—Indicator Diagram, showing Effect of Insufficient Passage-area, and Mode of measuring the Diagram.

of wire-drawing; but the particular engine from which the diagram, Fig. 83, which has a well-sustained admission line, was taken, was fitted with a governor acting directly upon the slide-valve, and controlling the speed by varying the point of cut-off, which is much better practice, though on account of the extra complication of such a valve gear it is hardly suited for the rough usage generally accorded to portable engines. As before mentioned, the diagram only shows the pressures upon one side of the piston. It is highly necessary that *both* sides should be indicated. Fig. 86, for instance,* shows the effects of unequal valve-setting; the valve spindle, or rod, is either too long or too short, and its adjustment would equalise the diagrams. The right-hand diagram shows an undue amount of compression and lead, while the one to the left is deficient in both respects as well as in the cut-off; and both suffer from an injurious amount of back pressure. The critical examination of the various lines of the Indicator diagram is a most interesting study; and the subject is most ably and thoroughly discussed in Mr. Charles T. Porter's "Treatise on the Richards Indicator."†

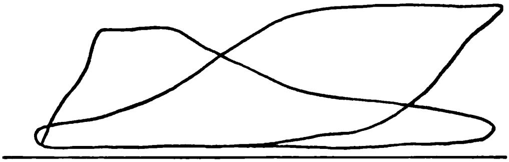

Fig. 86.—Pair of Diagrams, showing Unequal Valve-setting.

Our remaining space must be devoted to the means of deducing the *power* of the engine from the indicator diagram, and to a concise description of the instrument itself; the calculations of the actual quantity of steam and of heat expended in producing the power do not lie within the scope of the present volume, and must reluctantly be passed over.

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* Copied from Bourne's Handbook of the Steam Engine.

† Longmans.

Nominal, Indicated, and Effective Horse-power.—In common use there are at least three different methods of estimating the power of a steam-engine. Of these the first-mentioned, *Nominal* horse-power, is simply a conveniently elastic mercantile expression, calculated upon precisely the same principle, and probably due to the same master mind as the Board of Trade rule for passenger accommodation in steam-ships.

In each case the same exquisitely simple plan is adopted. So many inches of piston area or yards of deck *equal* so many horse-power—or passengers, as the case may be.

According to the Royal Agricultural Society's rule for portable engines, the nominal horse-power equals $\frac{d^2}{10}$ where d is the diameter of cylinder.

Of two engines having the same piston area the pressure or speed of the one may be double or half that of the other, without at all affecting the result. In practice, however, any engine having a cylinder from 9 to 10 inches in diameter is an 8 horse-power engine, and the simple rule above referred to is now modified; the constant 10 being replaced by t, which varies according to the state of trade, and at present stands at about 12·3.

Indicated Horse-power.—In a steam-engine the power exerted is always equal to the resistance overcome, and we can always measure that by the pressure upon the piston required to do the work. Total pounds of pressure upon the piston, multiplied by the number of feet the piston moves through in one minute, would evidently be exactly balanced by the same number of pounds *weight* lifted through an equal number of feet in the same time, supposing the engine to work without friction, and to be arranged for winding a weight up, as a colliery winding engine. The actual work of the engine may be to draw a train, propel a steam-ship, or drive a thrashing machine; but the work done can always be reduced to the unit of *foot-pounds*, or *pounds raised one foot high in one minute.* The unit of one foot-pound being rather inconveniently small, the expression *horse-power*, consisting of 33,000 foot-pounds, is adopted. Horse-power therefore is the product of

$$\frac{\text{Pounds per sq. in.} \times \text{area of piston} \times \text{speed of do. in feet per minute,}}{33{,}000}$$

and the indicator diagram, as a means of measuring the power of the engine, may be considered simply as a method of arriving at the *actual* average pressure upon the piston throughout the stroke. The *height* of the space included within the lines of the diagram, as before explained, represents at any given point with great exactness the cylinder pressure at that point. The *average* height of the diagram therefore will be the *average* pressure in the cylinder; which is what we require for the first factor in the formula above. This is usually found by the division of the diagram lengthwise into a number of compartments, generally ten, and measuring, by means of a scale, the vertical distance between the irregular bounding lines at the top and bottom about midway in each compartment. These measurements added together, and divided by the number of compartments, give a sufficiently near approximation to the average height of the diagram. An instrument consisting of a sort of parallel ruler, with eleven bars or strips, is usually sold with the indicator, and this apparatus, adjusted so that the first and eleventh bars coincide with the two ends of the diagram, at right angles with the atmospheric line, affords a ready means of dividing the length into ten equal parts.

Referring now to Fig. 85, it will be observed that the first division, by reason of its three irregular sides, has been subdivided into three compartments, and the mean of these three measures has been taken as the average 43·6 lbs., the scale employed being 30 lbs. to the inch of height. The second and succeeding compartments are each measured once only, the results being carried out to the margin so as to stand vertically over one another, for ease in adding up. The total 270·1, by removing the decimal point once to the left, becomes the average 27·0 (the ·01 may be neglected). Then as a 12-inch stroke and 125 revolutions per minute give 250 feet of piston—

$$\frac{\overset{\text{lbs.}}{27} \times \overset{\text{sq. inches}}{78{\cdot}74} \times \overset{\text{feet per min.}}{250}}{33{,}000} = 16{\cdot}06\,;$$

or, say, 16 indicated horse-power.* In this case we assume that the diagram correctly represents both ends of the cylinder. Both ends, however, should be indicated separately, and the mean of the two diagrams taken as the real average pressure. The scale of the diagram should be marked conspicuously upon it, and the further information shown in Fig. 85 should also be noted for future reference.

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* Assuming the area of piston to be 78·54 square inches, corresponding to a diameter of 10 inches.

When a large number of diagrams have to be taken from the same engine, much time in measurement and calculation may be saved by adopting two expedients. First, instead of measuring each compartment separately with the scale, a long strip of paper may be applied to each point, and the heights ticked with a pencil continuously along it. The number of inches of total length can then be measured with a two-foot rule, the scale being only employed for the last fractional part of an inch. Secondly, a good deal of the calculation may be done once for all by preparing a constant, thus—

$$\frac{\text{area of piston,}}{33{,}000}$$

which will be a decimal fraction (representing the horse-power for that particular engine at 1 lb. pressure and 1 foot of piston-speed per minute), only requiring to be multiplied by the average pressure taken from each diagram, and by the piston-speed observed simultaneously, to give at once the indicated horse-power.

If the piston-speed be so nearly uniform that it may practically be regarded as invariable, this factor also may be included in the constant, which will then only require to be multiplied by the pressure upon each diagram to give the result.

In our case the constant would be

$$\frac{78{\cdot}54 \times 250}{33{,}000} \text{ or } {\cdot}595,$$

which only requires to be multiplied by the 27 lbs. of the diagram to give the horse-power 16·0. It is a waste of time as a rule to give more than one place of decimals to the number representing indicated horse-power.

Effective Horse-power.—The effective horse-power differs only from the indicated horse-power in that it is taken at the crank-shaft by the friction brake or dynamometer,* and is less, consequently, by the power consumed in actually driving the engine itself, or *engine friction*, which is of course included in the indicated horse-power.

Description of the Indicator.—In principle, this instrument consists mainly of a small cylinder, having within it an accurately-fitting piston, the under side of which is in free communication with one end of the engine cylinder. The piston-rod of the indicator at its upper end carries a pencil arranged so as to mark upon a card, which slides backwards and forwards before it simultaneously with the movement of the piston. A stiff spiral spring, adapted to the pressure likely to be met with in the engine cylinder, is placed above the little indicator piston, so that the height of the latter, being dependent upon the compression of the spring, is an exact measure of the pressure acting beneath it.

If now the cock between the indicator and the engine be closed, the pencil, remaining stationary at its lowest point, will trace upon the moving card a horizontal line, and if the atmosphere be admitted under the indicator piston the line will denote atmospheric pressure. If the cock be opened and the card stopped, a *vertical* line will be drawn, the upper and lower extremities of which record the highest and lowest pressures respectively which have occurred during the stroke of the engine. The result of the simultaneous movement of card *and* pencil is the delineation upon the former of a diagram more or less approximating to those we have been considering. The pencil is only allowed to touch the card while one revolution of the engine is being performed. Fig. 87, taken from Forney's "Catechism of the Locomotive,"* shows several stages in the tracing of the diagram, during one-half a revolution. In No. 1 the card is just beginning to move in the direction of the arrow, and the piston-rod of the indicator has shot right up to the top, showing that the full pressure of the steam has just been admitted to the cylinder. No. 2 shows the admission line completed, and the rest various points in the expansion and exhaust lines. In No. 7 the card is just ready to move with the return stroke in the direction of the arrow, so as to draw the return exhaust line. The atmospheric line is visible in all the views, being always drawn before the diagram is begun. The form which the apparatus takes in practice is given by Fig. 88, which shows the improved instrument known as Richards' indicator, introduced by Messrs. Elliott Bros. of Charing Cross. The card, instead of being placed upon a flat surface and moved backwards and forwards in a straight line, is wrapped round the drum, which, being connected by means of the string (seen hanging from the lower part of it) with the cross-head or some reciprocating part of the engine, is partially rotated upon its vertical axis against the pressure of

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* A short description of the Friction Brake will be found at p. 136 in the present chapter.

* Spon.

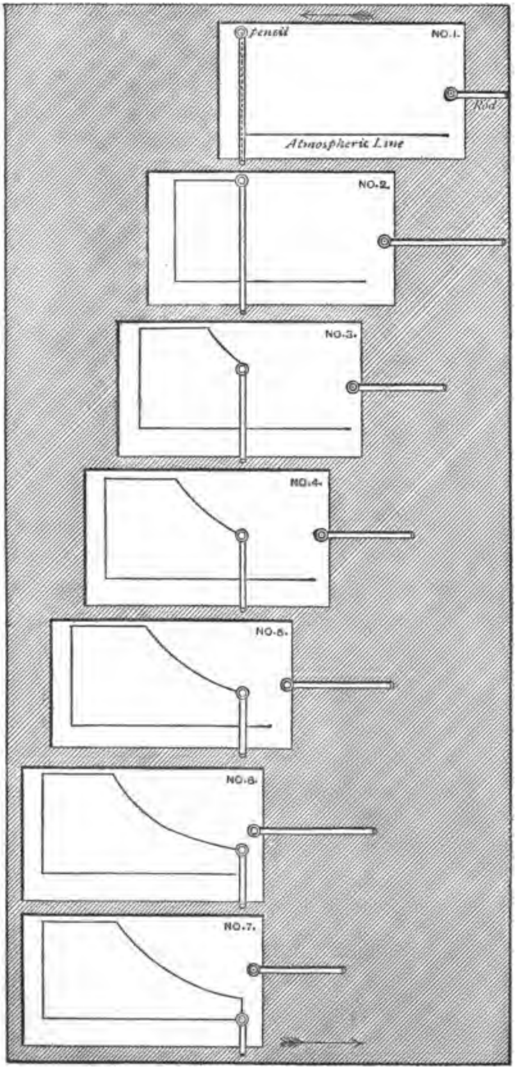

Fig. 87.—Series of Seven Positions of Indicator Diagram.

an internal coiled spring, which on the return stroke brings the drum back again to the starting point.

The pencil is not attached directly to the end of the piston-rod, but is carried by a parallel motion, with the object of multiplying its travel, the leading principle of this indicator being that instead of obtaining the requisite movement of the pencil (about 2½

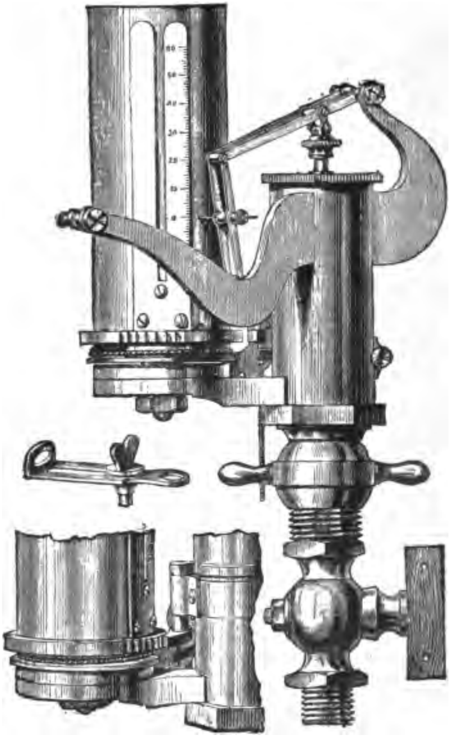

Fig. 88.—The Richards Indicator.

inches) by means of a very small piston with a very long range, and a correspondingly long and flexible spring, necessarily somewhat vague and uncertain in its indications, the piston is large and of small travel, with a very short and stiff spring, and the requisite range of pencil is obtained by multiplying-levers, forming a parallel motion. The pencil itself, a brass point for marking upon prepared metallic paper, is attached to the centre link of the parallel motion near the zero-point of the scale upon the drum.

A view of the union, or coupling between the indicator and the stop-cock, is given, by which it will be seen that differential threads are employed, the difference in pitch being sufficient to start the cone from its seat when the nut is unscrewed. The stop-cock is provided with a small hole in the side of the barrel, by which, when the plug is in the proper position, the air is admitted under the piston for drawing the atmospheric line.

By unscrewing the milled cylinder-cover the piston can be withdrawn and the spring changed if required. The spring used in any experiment should be adapted to the pressure in the cylinder of the engine: for example, in an engine where the boiler-pressure does not exceed 60 lbs., an 80-lb. spring should be used. Springs for these indicators are made to ten different scales, suitable for pressures varying from a vacuum to 175 lbs. per square inch; and for each spring a box-wood scale is provided for measuring the height of the diagram. The movement of the pencil with different springs varies from $\frac{1}{8}$ inch per pound pressure to $\frac{1}{56}$ of an inch per pound; the 80 lbs. spring, with which our diagrams, Figs. 83 and 85, were taken, having a range of 30 lbs. per inch. The most suitable method of connecting the indicator for portable engines is to employ a vibrating lever suspended some two feet above the guide-bars, and being at its lower end connected by a short link to one of the guide-blocks. A hole being bored in the upper part of the cylinder cover, an iron bend is screwed into it, and to this the indicator is fixed.

At a suitable point in the vibrating lever the cord for giving motion to the paper-drum is attached, care being taken that when the piston is at mid-stroke *the cord stands at right angles to the lever from which it derives its motion.* If necessary a supplementary lever, fixed at the proper angle for the cord, must be employed. The remainder of the instructions for using the indicator cannot be given better than in the maker's own words, as follows:—

To fix the Paper.—Take the outer cylinder off from the instrument, secure the lower edges of the paper near the corner by one spring, then bend the paper round the cylinder and insert the other corner between the springs. The paper should be long enough to let each end project at least half an inch between the springs. Take the two projecting ends with the thumb and finger and draw the paper down, taking care that it lies quite smooth and tight, and that the corners come fairly together and replace the cylinder. A little practice, with attention to the above directions, will enable any one to fix the paper very readily.

To connect the Cord.—The indicator having been attached, and the correct motion obtained for the drum and the paper fixed, the next thing is to see that the cord is of the proper length to bring the diagram in its right place on the paper—that is, midway between the springs which hold the paper on the drum. In order to connect and disconnect readily, the short cord on the indicator is furnished with a hook. On high-speed engines it is well to adjust the cord and take up the stretching as it takes place by tying knots in the cord. If the cord becomes wet and shrinks, the knots may need to be untied, but this rarely happens. The length of the diagram drawn at high speeds should not exceed 4½ inches, to allow changes in the length of the cord to take place to some extent, without causing the drum to revolve to the limit of its motion in either direction. On the other hand, the diagram should never be drawn shorter than is necessary for this purpose.

To take the Diagram.—Everything being in readiness, turn the handle of the stop-cock to a vertical position, and let the piston of the indicator play for a few moments while the instrument becomes warmed. Then turn the handle, horizontally, to the position in which the communication is opened between the under side of the piston and the atmosphere, hook on the cord, and draw the atmospheric line. Then turn the handle back to its vertical position, and take the diagram. When the handle stands vertical, the communication with the cylinder is wide open, and care should be observed that it *does* stand in that position whenever a diagram is taken, so that this communication shall not be in the least obstructed. To apply the pencil to the paper, take the end of the longer brass arm with the thumb and forefinger of the left hand, and touch the point as gently as possible, holding it during one revolution of the engine or during several revolutions if desired. There is no spring to press the point to the paper, and the operator, after admitting the steam, waits as long as he pleases before taking the diagram, and touches the paper as lightly as he chooses. Any one, by taking a little pains, will become enabled to perform this operation with much delicacy. Diagrams should not be taken from an engine until some time after starting, so that the water condensed in warming the cylinder, &c., shall have passed away. Water in the cylinder in excess always distorts the diagram, and sometimes into very singular forms. The drip-cocks should be shut when diagrams are being taken unless the boiler is priming. If, when a new instrument is first employed, the line should show a little evidence of friction, let the piston continue in action for a short time, and this will disappear.

As soon as the diagram is taken, unhook the cord; the paper cylinder should not be kept in motion unnecessarily, it only wears out the spring, especially at high velocity.

The Dynamometer, or Friction Brake, by which the effective or actual horse-power of an engine is ascertained, is a very simple apparatus, and may be shortly explained thus:—All physical work done is reducible to one standard—so many pounds lifted so many feet high in one minute.

In Trevithick's time it was the practice when an engine was to be tested to set up a pump with a column of pipes, and measure the water lifted through a given height in a given time. A less cumbrous arrangement suffices for our needs now, but we retain the same standard—the *foot-pound*—or pound raised one foot high in one minute. In effect, the dynamometer gives the engine under test a load of so many hundredweight to wind up continually at a given speed during the whole time of the trial (which may be several hours).

There is no need for a pit of unfathomable depth to wind the load out of, and no fear of over-winding. Around the fly-wheel of the engine (or upon a similar wheel to which the engine is connected) having a smooth rim, is placed an iron strap or band which can be tightened or loosened at pleasure. If a weight be attached to any point in this circumferential band, and the band fits the wheel loosely, the weight will remain hanging at the bottom ; now tighten up the band, and the weight will be carried round by the revolution of the wheel. But so adjust the tension of the band that the weight cannot either quite fall to the bottom or quite rise to the top ; it will be held at one side of the wheel in suspension, being exactly balanced by the friction; and then we may say—if the weight be 100 lbs., and the rim of the wheel is moving at 100 feet per minute—that the power which is turning the wheel is actually lifting 100 lbs. 100 feet high per minute, or doing 10,000 foot-pounds of work, which is roughly about one-third of an actual or effective horse-power.

CHAPTER VII.

HINTS TO PURCHASERS.

THE MANAGEMENT AND MAINTENANCE OF THE ENGINE IN WORKING ORDER.

As a general rule, if the inexperienced purchaser puts himself unreservedly into the hands of a first-class firm of manufacturers he may rely upon having a good article. In any case, however, it is as well to know what one is buying, and the few remarks we have to make upon this subject will, we are sure, be read with interest, and we hope not without profit, by the intending buyer.

In the first place then, if possible, buy a *new* engine.

A second-hand engine, however thoroughly it may have been repaired, is pretty certain to lack several modern improvements, and it is extremely difficult, except by the most searching, skilled investigation, to ascertain beyond all doubt the real condition of the boiler-plates.* A case occurred lately, within the experience of the writer, where a 16-horse portable engine was purchased second-hand for use in a brick-field. Fuel was tolerably cheap in the locality, and there was every reason to believe that the work could be done quite as well by an old engine in any reasonable state of preservation as by a new one fresh from the hands of the maker. The engine was bought, paid for, and set to work, after it had been closely examined by a working boiler-maker and the purchaser's engine-driver, who was supposed by his employer to know all about everything connected with portable engines. The engine had not been at work, however, more than two days, before a serious crack developed itself in the smokebox tube-plate. Of course the boiler-maker suggested "a patch," which was accordingly put on; but after considerable expense had been gone to without any satisfactory result a new tube-plate was decided upon. This, besides being an expensive article in itself when made to order, necessitated cutting the boiler about a good deal; and it was also determined, as the old set of tubes were not in very good order, that while they were about it a new set had better be procured and put in along with the tube-plate. Driving out the old tubes revealed the fact that, owing to an accumulation of scale, the firebox tube-plate was in very little better condition than the other one. Ultimately a new firebox, a new tube-plate, and a new set of tubes were put into a boiler not at all improved by the cutting out of the old rivets, and the condition of which in other respects was found to be, to say the least of it, exceedingly doubtful. Of course the expense of all this fell upon the purchaser; and it is hardly necessary to say that it very far exceeded the difference between the price he had paid and the cost of a new engine.

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* See Appendix.

When a portable engine has arrived at the stage of needing extensive repairs for the third or fourth time, it has been found by experience that it is only fit for the scrap heap.

In buying a new engine, it will be well for the purchaser to satisfy himself that he is getting the best possible engine for his money. There are many little points which, although not being absolutely defects in design, yet may render repairs to the engine more difficult and its maintenance more costly than there is any necessity for.

A case in point is the set of wheels upon which the engine stands. All manufacturers of portable engines allow the buyer the option of taking wood or iron wheels without any difference in the cost. The spokes, however, of the wooden wheels are pretty sure in a very few years' time to become loose in the cast-iron naves, owing to the heat of the boiler, particularly if they have not been made of thoroughly seasoned material. As it is of considerable importance to the life of the engine that it should stand firmly while at work, wheels wholly of wrought iron, which are practically indestructible, should always be specified in the order.

There are many makers who, while putting first-class work into the engine and boiler, are not sufficiently careful about some little matters which they consider of less importance. The iron plate of which the chimney and ash-pan are composed is nearly always much too light, with the consequence that these details require renewing while all the rest of the engine is practically as good as new, although this result may be very much hastened by improper treatment on the part of the engine-driver. The purchaser should see that the exhaust-pipe stands perfectly upright within the chimney, for if it is so placed as to deliver its steam against one side of the chimney, wherever the steam strikes the side, a thin place, and ultimately a hole, is certain to be formed, before the remainder of the chimney is half worn out. While on the subject, we should advise that the convex-plate which covers the top of the chimney be taken off if the engine is intended for thrashing. Sparks are far more likely to reach the stack if they are shot out sideways than if projected straight up into the air, in which case they are generally extinguished before they come down again. The tarpaulin or waterproof cover is hardly ever large enough to protect the engine from the weather. It ought to be wide enough to be tied right underneath the barrel of the boiler, and long enough to completely envelop the ends of the firebox and smokebox. The quality also of the covers supplied with the engines in general leaves much to be desired. In many cases very good engines are sent out with boiler-fittings, such as brass cocks and water gauges, not by any means of corresponding quality, and not nearly heavy enough. In fact, it is the exception rather than the rule for these to remain steam-tight after the first few months. The barrels of the cocks ought to *be* barrels, and not globes, and should give a bearing for the plug of not less than two inches in length. The plug should be kept in its place by a gland, and not by a nut and washer at the bottom.

Much may be saved in the cost of future repairs by choosing an engine having all its internal working parts readily accessible. It ought to be possible, for instance, to take the piston out without the necessity of drawing the fire and letting the steam down; therefore do not buy an engine where the back cylinder cover also forms a cover for the steam-jacket, or where the stop-valve and its seat are within the boiler, or where the throttle-valve is not readily accessible without having to lift the cylinder off the boiler when it becomes necessary to fit in a new valve.

The purchaser should have clearly pointed out to him how the removal of the slide-valve, stop-valve, and throttle-valve is to be effected, and satisfy himself that these parts, which are subject to considerable wear, can be renewed or repaired without difficulty. Do not buy an engine having an exhaust-pipe which passes through the boiler. This arrangement, much more used formerly than now, for the sake of neatness, is subject to two disadvantages: first, the exhaust steam carries away with it a very considerable quantity of heat from the boiler; and secondly, it is exceedingly difficult to remove it after it has been in use a few years. It ought to run along the top of the boiler outside.

The crank-shaft should be steel, and the brackets which carry it should be united in one casting, forming a saddle, and not separately attached to the boiler.

The boiler should have a large manhole, four mud-holes at the lower corners of the firebox, and a brass plug in the smokebox tube-plate for washing out.

The cylinder ought to have the steam-jacket formed by the insertion of a hard cast-iron liner, which can be renewed when worn out.

It is a good plan to have the safety-valves fixed upon the top of the cylinder and in free communication with the steam-jacket. By this means the air which accumulates in the jacket when steam is being raised can be blown out. The cylinder cocks should be arranged to entirely drain the cylinder of water, so as to avoid the possibility of the cylinder covers being broken by ice in frosty weather. The pump should be drained in a similar manner by a small cock screwed into the lower part of the barrel. The pump boxes should not be in one casting with the pumps, but of brass screwed into the barrel, so that if an accident happens to either of the boxes, or to the barrel, the one broken part can be replaced without incurring the expense of an entirely new pump. A guide should be fitted for the slide-valve spindle to work through, with a renewable brass bush, and all joint-pins in the excentric-rods and governors should be of steel, and so hard that they cannot be touched with a file, the joints themselves being case-hardened.

For thrashing and many other purposes it is necessary that the engine should govern itself perfectly—that is, maintain the same speed whether running light or with a full load on. The purchaser should assure himself of this by stipulating that he shall inspect the engine himself under steam. Unless the engine can be stopped by lifting the governor balls quite up to the top it will not govern, and is unfit to drive a thrashing-machine.

An arrangement for working with different degrees of expansion should be fitted to the excentric which works the slide-valve.

Lastly, the quality of the boiler-plates should be specified. The firebox should be of Low Moor or Bowling iron, and the remainder of B B Staffordshire, or equal quality, and the longitudinal seams of the barrel should be double riveted.

Setting the Engine to Work.

We will suppose that a satisfactory engine has now been purchased, and duly delivered upon the premises where it is to be made use of for driving a thrashing-machine or otherwise.

The engine should contain, packed up in the firebox and smokebox or elsewhere, every requisite for setting to work immediately.

Assuming the engine to have been placed upon the exact spot from which it is to drive, the first thing to be done (after putting the fly-wheel on) will be to level it crosswise. This may be done either by the indications of a spirit-level placed upon the crank-shaft or by a plumb-line held to the side of the fly-wheel, or by what is perhaps the simplest plan of all—putting the chimney up and sighting it by some neighbouring object known to be upright, such as a wall or the corner of a building. It is by no means necessary that the engine should be levelled in the other direction or lengthwise; the smokebox end may be, with advantage, as much as 3 inches higher than the firebox, thus not only giving a greater depth of water over the crown of the firebox, but giving an upward inclination to the tubes, by which a better natural draught is obtained.

The engine should now be secured in this position by wedging or chocking the four wheels with the wedges which will be found packed up in the engine for that purpose. These will require again tightening up into their final position after the engine has been at work a few minutes.

The boiler may now be filled with water through the hole which will be found (closed by a brass plug) in the centre of the manhole cover. A tin funnel is generally provided through which the boiler may be filled, or a hose pipe, if there be a water-tap near, may be employed with advantage. Do not forget to put the brass plug in again before getting steam up.

A water-gauge or glass tube for showing the level of the water will be found at the firebox end, and the water should be allowed to run into the boiler until it reaches about half-way up the glass tube. The water expands as it becomes heated, and when steam is up the water level will stand an inch higher in the glass than when the boiler is cold. See that the cocks connecting the water-gauge with the boiler are open. All the three handles of the water-gauge cocks should stand straight up-and-down.

The fire may now be lighted, but before doing so open the smokebox door, and see that nothing has been left inside by mistake. A tube-brush for sweeping out the tubes will be found inside one of them, and it should be taken care of. While steam is getting up the oil-can should be filled with good engine oil (it is economy to use the best that can be procured), and all the oil-cups upon the engine should be carefully examined to see that the wicks are properly adjusted. Inside each oil-cup will be found a small tube, and the cotton or worsted wick attached to a piece of thin wire should fit the tube loosely and go down it about an inch and a half, the remainder of the wick lying loosely in the bottom of the oil-cup. The cups may now be filled up and their covers carefully screwed on. The lubricator on the cylinder should be filled with melted tallow, or better still, with suet.

Now the leather strap for driving the governor may be put upon the pulleys, and the nut of the spring-balance of the safety-valve screwed down to the pressure required, which is marked upon the scale of the balance. There should be a brass tube or ferrule to prevent this being screwed down too far.

A water barrel or cistern must be placed between the wheels under the feed-pump and the two india-rubber hose-pipes screwed on in their places. Be particular to see that the leather washers in the brass unions of these pipes are in place, as otherwise the pump will not draw satisfactorily. The pipe with the perforated rose upon it is for the suction side of the pump, and fits upon the single valve-box; the other pipe fits the double box, and is used to convey the surplus water from the pump back again into the cistern, and to conduct a portion of the waste steam from the exhaust-pipe into the same receptacle, so as to warm the feed-water to some extent before it is pumped into the boiler.

The pump is always drawing water when the engine is running, and delivers it either into the boiler or back again into the cistern, or partially into both, according to the position of the regulating-cock upon the double valve-box. The other cock upon the waste-steam pipe is to control the amount of steam passing into the water.

We will suppose that the steam is now raised to a pressure of sixty pounds on the square inch, as indicated by the pressure gauge, the spring-balance safety-valve just upon the point of blowing off, and everything ready for a start. The fly-wheel should be turned round by hand once or twice to make sure that everything is free, and that nothing has been left in or near any of the working parts likely to cause damage when the engine is started. The steam may now be partially turned on and the engine allowed to turn round slowly for a few minutes with the cylinder drain-cocks open to clear the cylinder and exhaust-pipe of the condensed water with which they are pretty sure to be filled. When the steam issuing from these feels dry to the touch the steam may be turned fully on, and the drain-cocks closed.

For at least the first few hours the engine is at work, all the bearings should be constantly felt, and if any signs of heating occur the brasses must be carefully slacked back. Should this not prove effectual the engine must be stopped, the brasses taken out, wiped perfectly clean, and examined. If no marks of cutting be visible, they may be replaced (being careful not to screw or cotter them up too tightly), and the oil-cup retrimmed and filled up again. Particular attention must also be paid at first to the surfaces of the guide-bars, which are peculiarly liable to damage from grit or dust, especially if the engine be working out of doors.

It is not so generally known as it should be amongst engine-drivers that when the engine is running "inwards" (that is to say, with the crank, when at the top, moving *towards* the cylinder) the pressure of the crosshead is entirely borne by the upper guide-bars, which therefore require to be especially well lubricated when the engine is running in this direction. When the engine runs "outwards" the pressure is correspondingly taken by the lower pair of guide-bars.

The "warming-cock," before mentioned as being attached to the pump, should now be opened, and the exhaust steam allowed to flow into the cistern until the water is as hot as the pump can be induced to take it. Should any difficulty be experienced in getting the pump to work, it may either arise from the feed water being too hot or from one or other of the three valves being obstructed by some chip or piece of dirt drawn up from the feed water. If the pump feels hot to the touch it should be cooled by pouring water over it, the overflow cock opened to allow of the pumped water returning to the cistern, and the valve-boxes gently tapped with a wooden mallet. If this treatment be not effectual the suction-valve box may be opened and the valve lifted out, cleaned, and replaced; or it may be necessary to perform the same operation upon the delivery-valve box on the other side of the pump; but this should be done with great caution, because, although there is still another valve between this and the boiler, yet this latter valve may be itself the one which is not able to close fairly down upon its seat, in which case there might be a rush of boiling water from the delivery-valve box when the cap is removed, not only highly unpleasant to the operator, but attended with imminent danger to the boiler itself. Should this ever occur, do not waste another moment in attending to the pump, but instantly lift the fire out, before the water in the boiler sinks below the level of the firebox crown. It is true that a fusible plug is provided in the crown of the firebox, which is intended to melt and cause a rush of steam into the fire when the water sinks too low, but from various causes, such as being covered with hard scale, &c., this sometimes declines to act at the critical moment; so it is much better to place no reliance upon it under the circumstances we have described, but to draw the fire at once.

In working, the overflow cock of the pump should be set at such a point (very soon found by practice) as to admit continuously exactly the amount of water used by the boiler. When the steam pressure rises too high, however, a little more water than usual may be pumped into the boiler to avoid the annoyance and waste of steam being blown off at the safety-valves.

The steam should never be "throttled" by leaving the regulator handle only partially open when the engine is at work, even if the engine have very little work to do; the governor ought to be able to effectually control the speed of the engine without any assistance of that kind.

Another practice very much in vogue with agricultural drivers is to work the engine at a lower pressure than that for which it is intended, under a mistaken impression that they are thereby "saving steam." The exact contrary is the case: the engine should always be kept up to its full pressure just below the point at which the safety-valves begin to blow off.

If the work being done is below the full power of the engine, the excentric sheave which drives the slide-valve should be slackened, and moved round upon the crank-shaft so as to cut the steam off earlier in the cylinder and work with a greater measure of expansion. A pointer will generally be found upon the sheave and a scale of figures, thus—$\frac{3}{4}$, $\frac{5}{8}$, $\frac{1}{2}$, and so on. The pointer should be put to the lowest figure at which the engine will maintain its proper speed, and the sheave tightened up again. The engine will then be working at its most economical point, and by doing this, and warming the feed-water as much as possible in the manner we have described, a considerable saving in fuel may be effected.

When the amount of work to be done is continually varying, and the demand for power is consequently irregular, the most economical point for cutting off the steam varies also. It is clear that the engine cannot be stopped continually to adjust the excentric, and in such a case the engine would be better suited to its work if fitted with some form of automatic or self-acting expansion gear, such as can be attached at an additional charge of £1 or £1 10s. per horse-power to the engines of nearly all the best makers. This apparatus, without any attention whatever from the driver (except oiling and cleaning from time to time), is constantly on the watch for variations of load, and the smallest as well as the largest alterations in the amount of power required are instantly compensated for by a corresponding adjustment of the travel of the slide-valve, and the speed of the engine regulated to a great degree of exactness.

Management of the Engine while Running.—In order to work the engine with any degree of economy, it is an absolute necessity that the firing should be conducted on a proper system.

A careless fireman can easily neutralise the effect of all the improvements which have ever been devised by the makers of portable engines.

Proper proportion of boilers, relations of heating-surface to grate-area, carefully designed cylinders and slide-valves, expansion-gear and steam-jackets, all count for nothing in the presence of a fireman who treats the firebox as if it were a coal-cellar and shoots the coals in anyhow.

The golden rule for firing successfully and with economy may be stated in three lines—*The fire must be very thin and very bright, and the coal must be put on in small quantities and often.*

The thickness of the fire will vary so much in different engines and under different conditions, that it is not possible to lay down a hard and fast rule for the thickness, which will be easily found by experiment; but the thinnest fire with which the engine can be made to keep steam is the right one. The fire should be gradually deeper from the centre to the sides of the firebox, and especially at the back, right under the door. If the fire is collected in a heap in the middle of the grate, a stream of comparatively cold air is continually passing up all round the walls of the firebox, which is highly injurious to it, and the firebars also suffer from the additional weight imposed upon them at their weakest point, the centre.

When the fire is just burnt bright the steam pressure will show signs of rising. A new thin layer of coals will check this for a few moments and then the firebox will be filled with flame and the pressure will look up again.

By means of the damper upon the ashpan it ought to be possible to keep the pressure for hours at a time without its varying more than a couple of pounds in either direction. When absolutely necessary, the amount of feed-water entering the boiler may be increased or diminished to suit the circumstances of the moment, but this is not good practice, and the driver's aim should be to keep a constant pressure with a constant feed and constant firing.

Never let the fire burn into holes, and do not knock and torture the fire about with a rake, or keep turning on the steam-jet. These are the resources of a bad fireman, who has allowed his air spaces to become clogged up by accumulations of clinker. The shovel and the damper are the only tools which ought to be used while the engine is running,

Preparing to Stop.—For some time before a stoppage, the water level should be allowed to rise to the extent of a couple of inches in the glass, if the engine will stand so much, and no more coal should be added; but when the pressure begins to drop, the fire may be knocked together a little, and evenly spread over the bars. Now it will burn up bright and clear, and the engine will steam well until there is hardly any fire left at all. When the engine is stopped, the fire should be all pushed over with a rake under the tubes, so as to leave half the grate exposed. The engine may now be safely left for half an hour or even more if necessary, and the pressure will not vary a pound if this has been cleverly done.

Assuming that the engine has to run on again in an hour from the stoppage, some fifteen minutes before starting-time the exposed half of the bars ought to be thoroughly pricked, that is, the air spaces cleared out, the fire moved over, and the same process repeated with the other half of the grate. When the grate is clear, the fire may be once more spread evenly over the bars and all the clinker lifted out, and a couple of layers of fresh coal added. If there be a steam-jet, now is exactly the time when it may be used with advantage. (The steam-jet should never be used, or the engine allowed to run, when the whole or any part of the grate is left uncovered by the fire, because the current of unwarmed air drawn through the tubes by the action of the steam in the chimney always induces leakage at the point where the tubes fit into the fire-box.) When the time for starting comes, if these directions have been carried out, there ought to be a good fire just at its best and ready for anything. As soon as this is done, and the dirt got rid of, the engine should be wiped down all over, and all the oil-cups refilled ready for starting.

Maintenance of Engine in Working Order.—Before the engine has been at work very long it is pretty sure to show signs of leakage at the glands, which must from time to time be tightened up gently. When the existing packing is evidently worn out, the glands must be drawn out of the stuffing-boxes, and the old packing taken out by means of a piece of wire bent like a corkscrew, or anything else that will answer the purpose, and a new packing, consisting of greased hemp or flax, plaited into a tight rope, must be coiled round the rod and driven in, one coil at a time, by a piece of hard wood shaped like a chisel. If anything of metal be used for this purpose it is exceedingly liable to damage the rod. The stuffing-box should be filled nearly full and the gland screwed down upon it, but only just so tightly as will prevent the passage of steam. Round each rod, and close to the gland, a ring of hemp should be twisted or plaited, and secured to the gland by tying. This is called a "swab," and has the effect of keeping the rods clean and bright.

As the brasses and the excentric-straps wear, which will be indicated by the knocking or thumping which will be heard, they must be tightened up, cottered or screwed as the case may be.

When the two edges of the brasses come together, a little must be filed off each edge with great care.

It is advisable occasionally to test the slide-valve and piston, to see if they continue perfectly steam-tight. This is a very simple matter, and easily done. To test the slide-valve, the engine is placed at a little over half-stroke, just where it will not start when steam is turned on. If now a rush of steam through the exhaust-pipe is perceptible, by listening when the smoke-box door is open, it is a proof of leakage past the slide-valve.

The piston may be tested by placing the engine upon either or both the dead centres, that is to say, with the piston at one end or other of the cylinder; and in this position, in which the engine cannot start, turning the steam full on, and listening at the blast pipe as before. The steam which escapes up the chimney in both of these cases, and which of course goes on all the time the engine is at work, is *lost*, and it is for the owner to decide as to when he is justified in calling in the services of a fitter to put the matter right. Sometimes, however, the piston may be put right by the engine-driver, as when the rings require setting up. To effect this the piston should be taken out and to pieces. The rings should be tried separately in the cylinder, and if they do not "spring" properly, so as to fit it with a moderate degree of tightness, they should be very carefully hammered all round the inside, of course taking care not to break them in the process or to damage the edges. If a glut be used, the spring by which it is set up should be strengthened, either by bending or by packing. The rings fit the cylinder properly when each one separately is just so tight in the bore that it may be pushed and pulled backwards and forwards by the fingers.

A leaky slide-valve can only be made tight by scraping, which involves the attendance of a fitter with a surface-plate.

Do not suffer a leak which may show itself in any of the cylinder joints to continue. At the first possible opportunity, if it be in one of the covers, take the cover off, scrape the red lead from it, and make the joint over again with a couple of thicknesses of brown paper, cut to the proper shape, and well painted on both sides with oil-paint, or boiled oil. This makes a cleaner joint, and the materials for it are more readily procured than the ordinary red-lead joint. Above all, *keep the engine clean.* This simple rule, if thoroughly carried out, will do more to cut down the expenses of maintenance than would be thought possible; therefore owners should encourage their drivers to keep the paint, the polished work of the motion, and the brass work bright and shining, and provide their men with cotton waste, oil, and emery-cloth (the latter to be used sparingly, however) to enable them to do it.

The man who takes a pride in keeping his engine spotless externally will be much more likely to keep his boiler clean and free from scale by frequent washing out, to the great benefit of his employer's pocket, than he who is content to let the engine work amid dirt and grit, with steam leaking from every gland, the brasses loose, and the connecting-rod thumping every time the crank passes the centre.

Care of the Boiler.—It is an imperative necessity, if the engine is to be kept out of the repairing shop, that the boiler be kept perfectly clean, both inside and out.

A boiler may be destroyed in two ways: it may be torn to pieces in an instant by an explosion, or it may be done to death just as effectually, but more quietly, by the slower operation of corrosion; the firebox may be ruined by overheating, caused by dirt and scale filling up the water space around it, and thus keeping the water away from the plates—which for want of it become red hot and unable to resist the pressure inside, and consequently bulge out between the stays like a cushion, and crack. Upon the other side of the same plates—the fire side—very probably the process of destruction by corrosion is slowly going on—in this way. The driver, we will say, has discovered that by throwing water into the firebox when the fire is all but out, the clinker (or incombustible matter which adheres to the fire bars) by its sudden contraction will of itself become detached without the trouble of breaking it away with the slice or chisel bar. The wet ashes remain all night like a damp sponge in contact with the surface of the firebox, insidiously eating it away, and the space left for the expansion of the firebars all round the box becomes filled up with a solidified mass as hard as iron, which causes the daily expansion of the bars to become a pressure upon the plates. Thus tortured, as by a rack, is it to be wondered at that the unfortunate firebox, overheated, corroded, distorted, does not last out half its days? If cleanliness be at all times a Christian virtue, it is conspicuously so when exhibited by an engine-driver in charge of a portable engine-boiler.

No leakage from any mud-hole, especially from the one in the smokebox, should be allowed to continue beyond the next blowing-off day. A continual oozing from any hole or joint about the boiler will in a surprisingly short time eat away the plate all round the leaky place, and in the case of a mud-hole, when the plate all round is weakened and irregular in surface from the effects of corrosion induced by leakage, a tight joint for the future can only be insured by the exercise of the greatest care. Occasionally a firebox stay may begin to leak either inside or outside the firebox; this should be stopped at once by caulking. Once a week the boiler should be blown off after the steam pressure has been allowed to escape by the safety-valve. (Never run the engine without a fire in the grate for the purpose of getting rid of the steam.) If a "mess" upon the floor or ground is not of consequence, it is as well to knock in a mud-lid and let the water out through that, instead of by the blow-off cock, as there is a considerably better chance, on account of the rush of water, of loose matters being carried away.

Fortnightly, or every three weeks at furthest, according to the kind of water used, the entire interior surface of the boiler firebox and tubes should be thoroughly raked or scraped out, and every possible means used to remove the scale, which is very easily washed off when soft, but very difficult to remove after it has hardened. As scale is a non-conductor, a very much more intense fire has to be kept up to communicate the same amount of heat to the water, when the surfaces of firebox and tubes are coated with it, than if they were clean; and when any considerable thickness has accumulated in the endeavour to keep up steam by forcing the fire, the plates and tubes are likely to become overheated and leaky, not only involving a great loss in fuel, but in all probability incurring a serious expense for repairs.

The front of the firebox, around and between the tubes, should receive particular attention. This can generally, in small engines, be reached by a short scraper used from the man-hole.

If a hose and water pressure are not available, it is a good plan to have a small force-pump with which to project a stream of water upon any part where the scraper cannot reach. Failing either hose or pump, buckets of water should be dashed in violently through the man-hole. Every time the boiler is cleaned the scale should be carefully scraped off the top of the fusible plug, otherwise it may fail to act in time of need.

The tubes should be brushed through every morning, and if the coal be of a smoky nature, even in the middle of the day, when the engine is stopped and the fire low.

Two or three times a week at least the firebars should be dropped into the ashpan and the firebox brushed round with a stiff brush.

Wet ashes should never be allowed to remain in the ashpan.

Do not keep firebars in use after they have been bent, or allow a slovenly driver to bend them by keeping the ashpan full of ashes, thus placing the bars between two fires and impeding the draught.

If a gauge-glass breaks, replace it at once, and always keep a spare one, with a couple of india-rubber rings upon it, ready for immediate use. While the glass is being put in, the test-cocks may be used to ascertain the height of the water. When the water level is where it should be, steam should issue from the upper cock and water from the lower one.

Finally, we should advise the owner to check the daily or weekly consumption of coal, and compare it from time to time with the amount consumed when the engine was new, or known to be in good order; and insist upon the driver keeping the engine up to the mark.

These observations, which are the result of experience derived from the examination of large numbers of engines and boilers sent in for repair, will, we believe, be the means of saving some pounds per annum in repairs and fuel in every case where they are fully carried out.

A Portable Boiler Explosion.*

"We fancy that the accompanying engravings will interest our readers. They are copied from an official report made under the Boiler Explosion Act of 1882 by the Board of Trade.

"The explosion occurred at 4 P.M. on the 20th of May, 1886, at the Station Saw Mill, Stow, Midlothian. The saw mill belongs to Messrs. George and John Brown, George Brown being the managing partner, and also attending to the boiler and engine. No person was killed or injured. This was a portable engine and boiler of the usual agricultural type, the boiler being of iron and single riveted throughout. Length of boiler over all, 9 feet 6 inches; length of barrel, 6 feet by

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* From *The Engineer*, Sept. 3rd, 1886, p. 186.

2 feet 6$\frac{3}{4}$ inches internal diameter, composed of two plates $\frac{5}{16}$ inch in thickness with longitudinal lap joints, the rivets being $\frac{3}{4}$ inch diameter, spaced two inches apart, and the width of the laps 1$\frac{5}{8}$ inch, the joints being at the top and bottom of the barrel. Firebox: length, 1 foot 8$\frac{1}{2}$ inches; width, 2 feet 5 inches; height, 2 feet 10 inches. Fire-box casing: length, 2 feet 4 inches; width, 3 feet 1 inch; height, 4 feet 3 inches; of $\frac{3}{8}$ inch plates, the two being joined at the bottom with an N iron. Firebox stays $\frac{7}{8}$ inch diameter, spaced 6 inches by 6 inches. Top of firebox stayed with three T-iron girders, each 3$\frac{3}{8}$ inches by 3 inches by $\frac{1}{2}$ inch. The girders are riveted

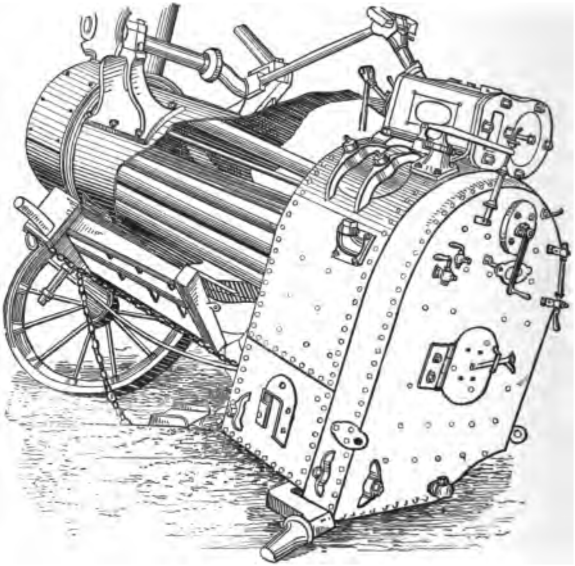

Fig. 89.

to the crown plate with four $\frac{3}{4}$-inch rivets, passing through thimbles $\frac{3}{4}$ inch in thickness, and the ends of the girders bent downwards $\frac{3}{4}$ inch, to form feet. There are also two longitudinal stays $\frac{7}{8}$ inch diameter in the steam space. The tubes are $2\frac{3}{4}$ inches external diameter, and twenty-six in number, but none of these are stay tubes. The whole of the fittings were in good working order. Clayton, Shuttleworth, & Co., engineers, Lincoln, is inscribed on the name-plate. The engine was bought by the present owners on the 23rd December, 1884, from Messrs. Graham & Co., Dobbies-loan, Glasgow. Mr. Graham has no record of the person he bought it from or date of pur-

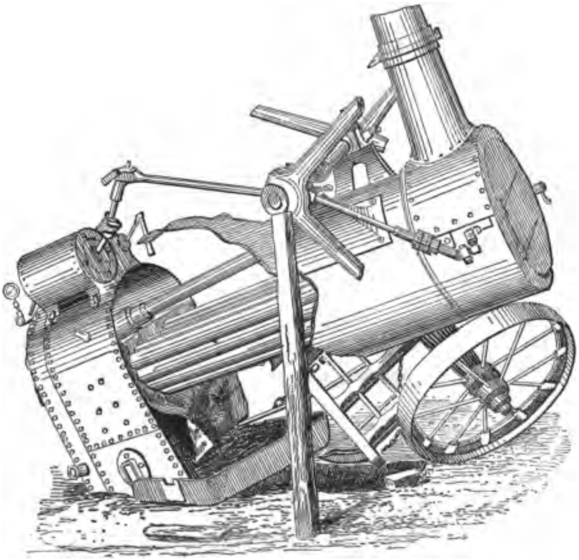

Fig. 90.

chase, neither does he know the age of the boiler. There is no number on the boiler or engine, and not even a letter, number, or mark on any of the working parts of the engine by which its history might be traced. The firebox casing had been patched, and new firebox stays fitted at some time. No repairs have been done to the boiler since Messrs. Brown bought it; but some small repairs have since been made to the engine. Mr. Jas. Thomson, millwright and engineer, Stow, made an external examination of the engine and boiler and also tried it under steam at 70 lbs. pressure at the time Messrs. Brown bought it. Mr. Thomson has also seen the doors off once since that time, when making repairs to the engine. The boiler was not insured.

"The engine was stopped a few minutes before the explosion, when the steam pressure is stated to have been 40 lbs. The barrel of the boiler was rent from end to end at the bottom, and torn from the firebox casing; it is also torn circumferentially, immediately abaft the saddle plummer blocks of the engine and the wrought-iron bracket plate for attaching the front wheels. This portion of the boiler was separated into two main and several small pieces, some of which were blown through the roof of the shed into the adjoining field. The throat plate was torn in shreds from the firebox casing and stays. One longitudinal stay was broken. The front tube plate was torn from the angle-iron ring at the bottom, and the bottom tube ends were started. The engine and carriage were broken in pieces, and the wooden shed was demolished. Fortunately, all the men were employed a little distance off at the time of the explosion, and so escaped injury.

"This explosion was due to grooving and wasting at the edge of the inside lap of the bottom longitudinal joint, the plate being reduced in thickness throughout the whole length of the barrel from a maximum of $\frac{3}{16}$ inch down to $\frac{1}{32}$ inch and under, until it was unequal to sustain the load due to the ordinary working pressure of 50 lbs.

"The barrel was encased with sheet iron over wooden lagging, which was not removed to examine the shell externally when Messrs. Brown bought it. Neither were any of the tubes removed to examine the shell internally, both of which should have been done to make an efficient examination. The simple precaution of testing with water pressure was not even taken. The boiler and engine were tested with a little extra steam pressure, and this proving satisfactory, all was thought to be well; but at the same time this serious grooving must have existed in the barrel. In the opinion of Mr. Lewis, the Board of Trade inspector, the grooving must have commenced years ago, and it is a long time before such grooving becomes dangerous. Judging from experience in the investigation of three explosions of boilers of the same type, and due to the same cause, it is found that the grooving action is not generally very rapid, and that proper periodical examination would not fail to discover it. With the exception of this grooving, the boiler was in fairly good condition, and would have worked for years longer."

In reproducing from *The Engineer* the engravings and description of the Stow explosion, it is only necessary by way of comment to point out that the method of testing the strength of a doubtful boiler by steam pressure is perfectly analogous in principle to, and not a whit less reckless and dangerous in practice than would be the testing the quality of dynamite by attempting to explode it with a percussion cap.

A portable-engine boiler may be safely and efficiently tested by hydraulic pressure without the use of a special apparatus, by the following simple means:—

Fill the boiler quite full of water, closing all outlets, and by means of the ordinary feed-pump (turning the fly-wheel round by hand) pump the boiler up to the required test-pressure. It is advisable, however, to make sure beforehand that the pressure-gauge on the engine is reliable, especially if it be an old one. The large-end of the connecting-rod may be taken down to avoid the useless labour of moving the piston.

A boiler should always be tested to double the pressure at which it is intended to work, and in purchasing an old engine the vendor should be required to do this in the presence of the buyer.

If the boiler runs and leaks at every joint under this test the engine is dear at any price, and should be refused.

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